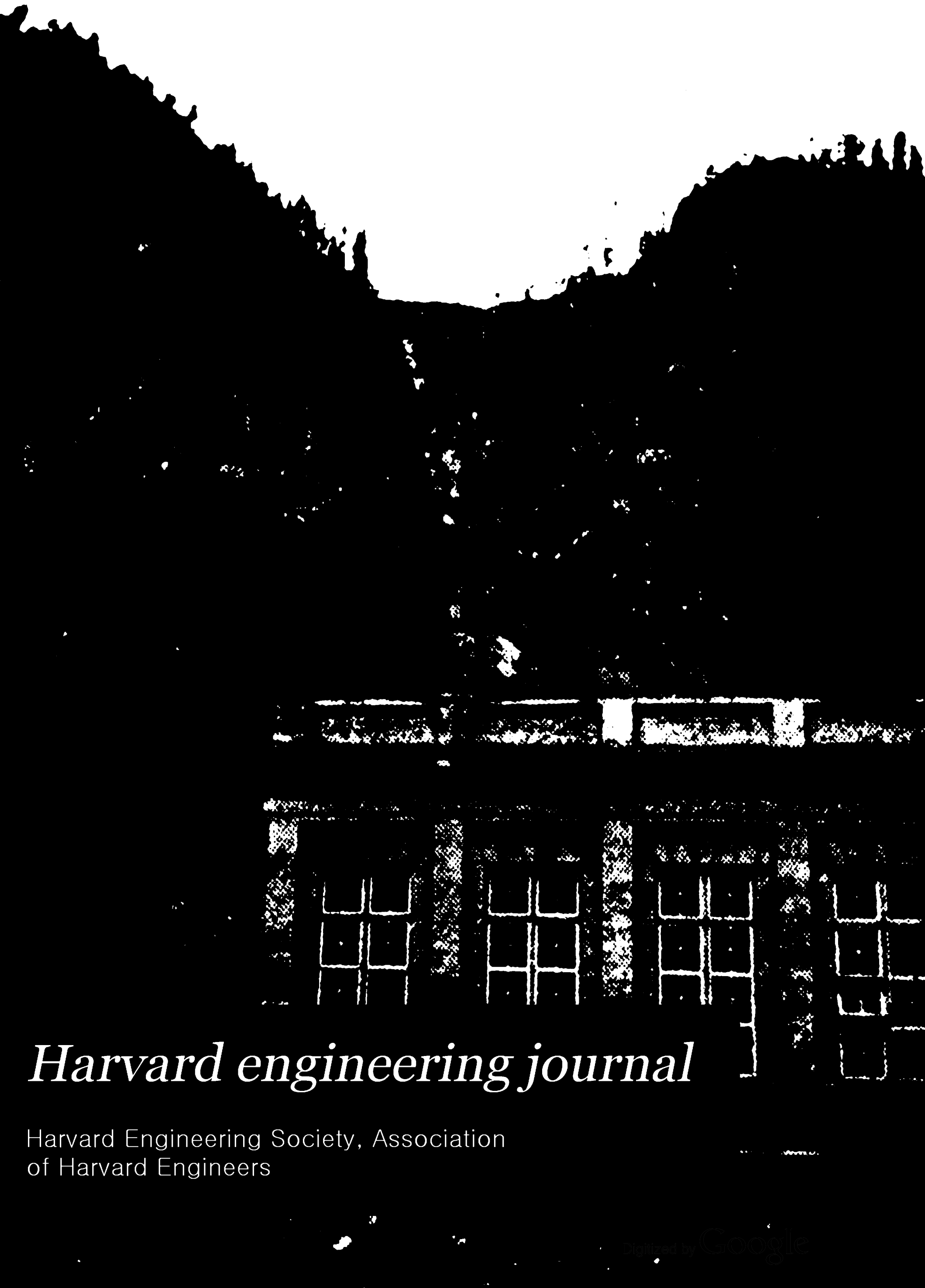

# Harvard engineering journal

Harvard Engineering Society, Association of Harvard Engineers

APRIL, 1909

# HARVARD ENGINEERING JOURNAL

A QUARTERLY
DEVOTED TO THE INTERESTS OF
ENGINEERING AND ARCHITECTURE
AT HARVARD UNIVERSITY

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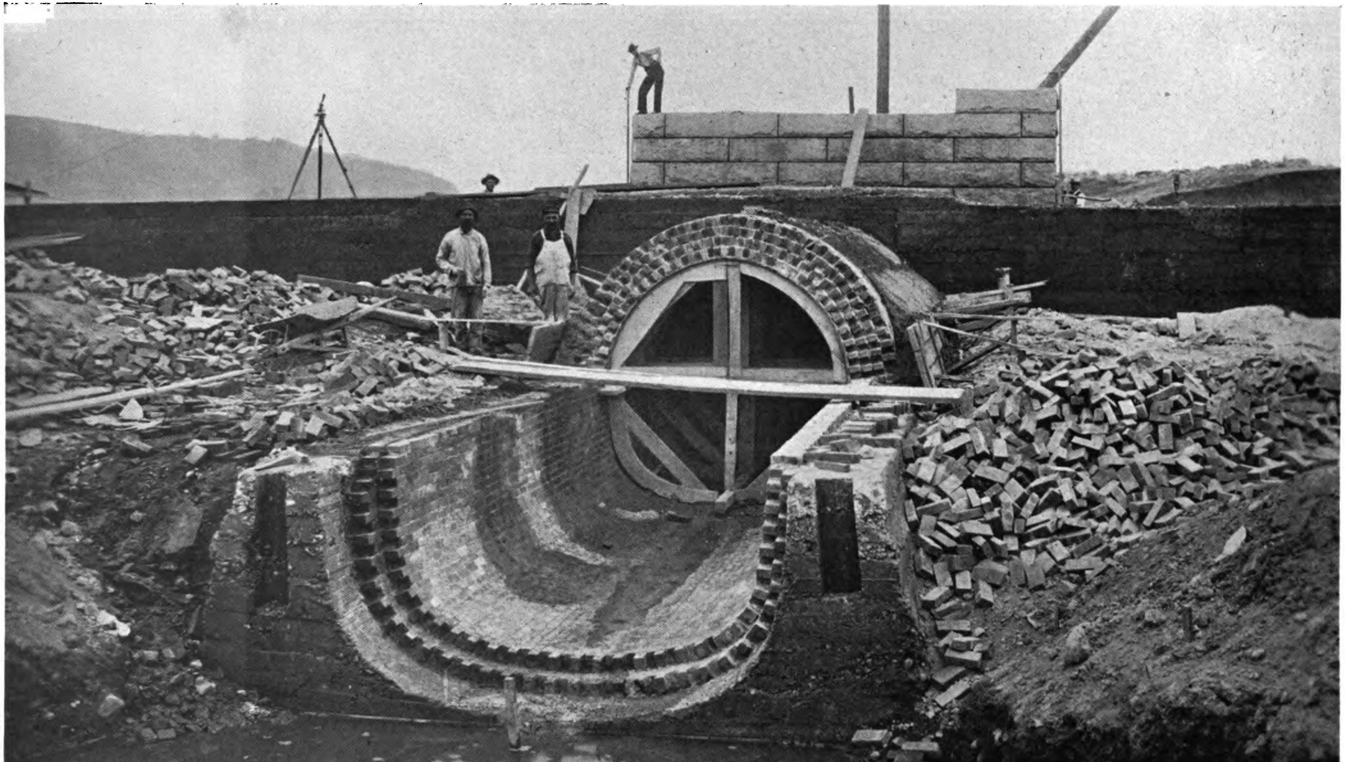


(*See page 240.*)

WINTER STREET DAM. (Waste Way Conduit, looking north)

HARVARD
ENGINEERING JOURNAL

A QUARTERLY

Devoted to the interests of Engineering
and Architecture of Harvard University

VOL. VIII APRIL, 1909 NO. 1

# THE ANALYSIS OF COAL

BY LIONEL S. MARKS

The composition of coal can be stated in terms of two different sets of constituents, one giving information as to the general characteristics of the fuel, the other giving the actual amounts of the chemical elements in the combustible part of the coal. The former method of stating the composition is commonly known as the "proximate" analysis, the latter, the "ultimate" analysis of the fuel.

Of these two methods the proximate analysis is by far the most commonly used and the more easily made. It separates the coal into five constituents; namely, (1) moisture, (2) volatile combustible matter, that is, volatile matter other than moisture, (3) solid or fixed carbon, (4) ash or incombustible matter, and (5) sulphur. The method of carrying out this analysis has been standardized by the American Society of Mechanical Engineers. The moisture is determined by observing the loss of weight of a small, finely divided sample when kept at a temperature of 220° F. for one hour; the volatile combustible matter, by observing the loss of weight of a dried sample contained in a platinum crucible with a closely fitting lid and subjected for three and a half minutes to the heat of a Bunsen flame and then for another three and a half minutes to the heat of a blast flame; the fixed carbon by observing the loss of weight of the residue of the previous operation when slowly but completely burned; what remains from this operation is the incombustible matter or ash. The sulphur

has to be determined from another sample by a series of chemical operations which are preferably to be entrusted to a trained chemist; the so-called Eschka method is commonly employed.

This standard method of making the proximate analysis has recently been investigated by a Committee of the American Chemical Society, and it appears that when the blast flame is applied to drive off the volatile combustible matter, particles of solid carbon go off with the volatile matter. It is now becoming the practice to discard the blast flame in determining the volatile combustible matter and to subject the sample for seven minutes to the full flame of a Bunsen burner. The analyses discussed below were made in this manner.

The proximate analysis has become of particular interest of late in connection with the new practice of buying coal on specifications with penalties or bonuses depending on the differences between the coal supplied and that specified. Such specifications usually define the composition of the coal contracted for, as for instance, moisture 1 per cent, volatile matter 22 per cent, sulphur 1 per cent, and ash 7 per cent, and then give a scale of increase or decrease of contract price according as the tested samples show less or more than the stated amount of each constituent. Moreover, the proximate analysis is the simplest basis for the classification of coals; the division into anthracite, semi-anthracite, semi-bituminous, bituminous, etc., being in a general way based on the content of the volatile matter; lignites and peat, however, are classified from external physical characteristics rather than from composition. The proximate analysis does not give nor does it permit the deduction of the calorific value of a fuel; there is certainly no relation between the two. For the determination of the calorific value of a fuel the best experimental method is that using the bomb calorimeter — an instrument of great precision. The proximate analysis (excluding sulphur) and the calorific value are readily and accurately determinable by an engineer who has some knowledge of experimental methods.

The proximate analysis does not give sufficient information for certain purposes of the engineer. If the heat loss up the

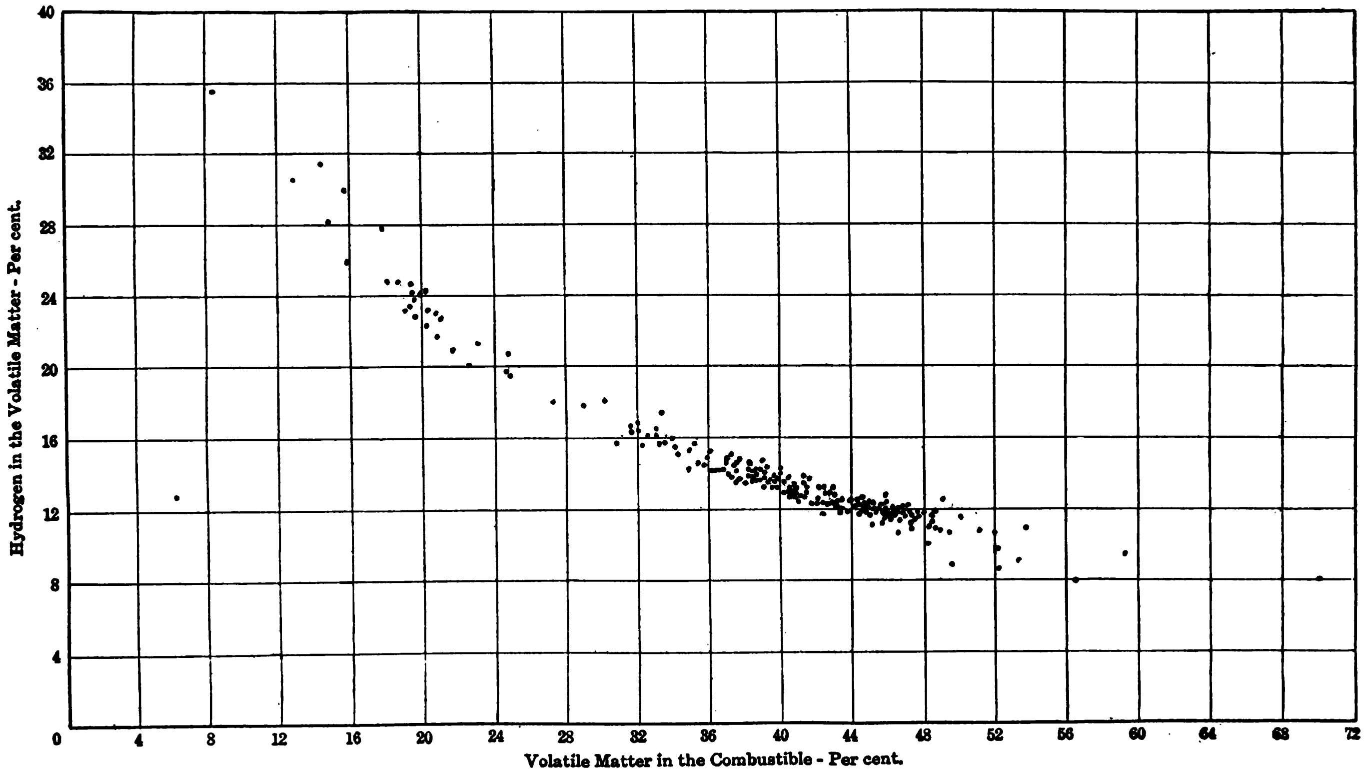



Fig. 1. SHOWING THE PERCENTAGE OF HYDROGEN IN THE VOLATILE MATTER OF COAL.

chimney during a boiler test is to be calculated accurately, or if the efficiency of a gas producer is to be calculated on a lower heat basis, the hydrogen content of the coal must be known. If the volume or the weight of gas generated per pound of coal in a gas producer is to be calculated from the known composition of gas, the carbon content of the coal must be known. The determination of these two elements, together with the oxygen, nitrogen, sulphur, and ash present in the fuel, is the so-called "ultimate analysis." The complete analysis requires three operations, (1) the slow combustion of the coal and the absorbtion and weighing of the $CO_2$ and $H_2O$ that are formed, (2) the determination of the nitrogen by Kjeldahl's method, and (3) the determination of the sulphur by the Eschka or other method. The oxygen is found by difference. The first operation, which gives the amounts of hydrogen and carbon present in the coal, requires a degree of manipulative skill and an experience in chemical investigation which is seldom possessed by the engineer. Consequently the ultimate analysis is usually entrusted to a chemist and is necessarily costly.

The ultimate analysis can be used for calculating the approximate calorific value of the fuel. The Dulong formula, which is most used for this purpose, is

$$Q=14550\,C + 62000\left(H - \frac{O}{8}\right) + 4000\,S$$

where Q is the calorific value in B.T.U. per lb. of coal, and C, H, O, and S are the weights of Carbon, Hydrogen, Oxygen, and Sulphur respectively per pound of coal.

The tests described below give a good basis for ascertaining the accuracy of the Dulong formula. They show very good agreement between the calculated and the experimental heat values; the calculated values are liable to be about one per cent low.

The United States Geological Survey has had under way since 1903 a series of tests of fuels intended to include samples of coals and lignites from every important field in the United States. These tests include among other things the

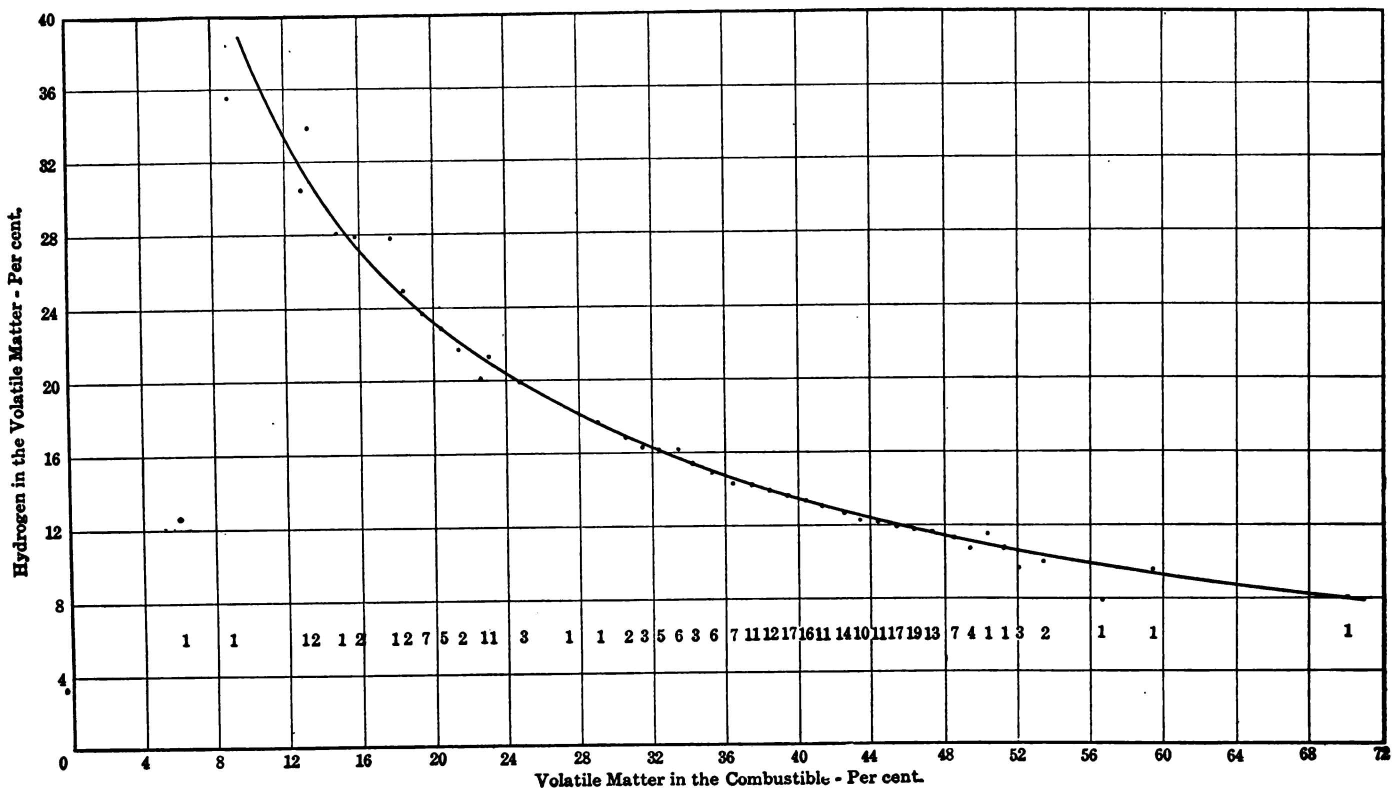



FIG. 2. SHOWING THE AVERAGE PERCENTAGE OF HYDROGEN IN THE VOLATILE MATTER OF COAL

proximate and ultimate analyses of the fuels. There have been published* so far the results of the tests of about 240 different fuels collected from 28 states and territories, representing every kind of fuel from anthracite to peat and with a range of volatile matter from 6 to 70 per cent. The analyses have been made under such conditions as to command complete confidence. They form by far the most important body of tests of coal that have ever been made and afford a foundation on which it should be possible to base some general conclusions as to the fuels occurring in the United States.

The writer has made a complete study of these analyses for the purpose of ascertaining what relation, if any, exists between the proximate and ultimate analyses of coal. This study shows that, for the fuels existing in the United States, it is now possible to determine the hydrogen content of the coal from the proximate analysis alone. As a result of this it appears also to be possible to make the ultimate analysis of coal in a comparatively simple manner — avoiding the difficulty and cost of the usual method of procedure. The principal objects of this article are: (1) to show the relation between the hydrogen content of coal and the volatile combustible matter, and (2) to outline a simplified scheme for the ultimate analysis.

The analyses are published in the form shown in the following example:

Kentucky Coal No. 6. Bulletin No. 290, page 126.

| Proximate Analysis. | | Ultimate Analysis. | |
|---|---|---|---|
| Moisture | 5.12 | Ash | 2.76 |
| Volatile Matter | 36.49 | Sulphur | 0.57 |
| Fixed Carbon | 55.63 | Hydrogen | 5.47 |
| Ash | 2.76 | Carbon | 77.20 |
| Sulphur | 0.57 | Nitrogen | 1.45 |
| | | Oxygen | 12.55 |

(The sulphur in the proximate analysis is taken into account twice — part of it escapes with the volatile matter, part remains with the ash.)

*United States Geological Survey. Professional Paper No. 48 and Bulletins No. 290 and No. 332.

The moisture and the ash in a coal are to some extent accidental and will vary from sample to sample taken from the same seam of coal. The analyses have all been recalculated so as to express the composition in terms of dry combustible, eliminating the moisture and ash entirely. For making this recalculation it was assumed that the sample used for the ultimate analysis had the same percentage of moisture as the sample used for the proximate analyses. For the example given above, for instance, there is 5.12 per cent of moisture present, of which one-ninth is hydrogen and eight-ninths oxygen; these amounts of hydrogen and oxygen have to be substracted in correcting the ultimate analysis for moisture.

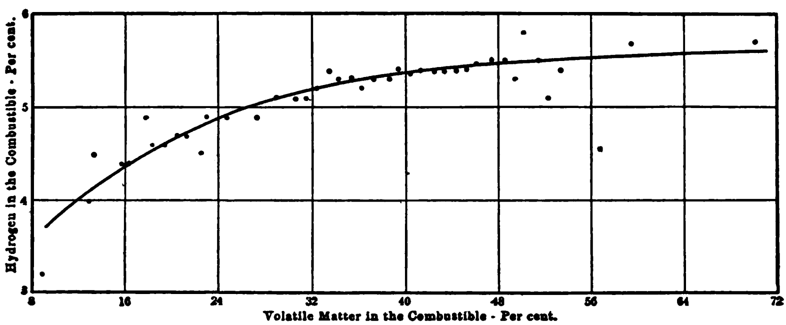



FIG. 3. SHOWING THE HYDROGEN AS A PERCENTAGE OF THE TOTAL COMBUSTIBLE MATTER IN COAL

In order to find if there is any relation between the hydrogen content of a coal and the volatile combustible matter Fig. 1 has been plotted. The abscissæ are the percentages of the volatile matter in the combustible; the ordinates are the percentages of hydrogen in the volatile matter (not in the combustible). In the region from 36 to 48 per cent of volatile matter the points lie so close together that it is not possible to show them all in a figure of moderate dimensions. It will be seen that the plotted points lie very close to a smooth curve. To draw the curve accurately the average position of the points was calculated for each one per cent range of volatile matter and these average points are given in Fig. 2. Each point between 36 and 48 per cent volatile matter is the average of from 10 to

19 analyses; over 50 per cent, most of the points represent one analysis only; from 18 to 32 per cent, the only points not very close to the curve represent one analysis only; below 18 per cent, each point, with one exception, represent but one analysis. The number of analyses of which each point is the average is given in the diagram.

The percentage of hydrogen in the combustible has also been calculated and the results averaged for each range of 1 per cent in volatile matter. The average points are plotted in Fig. 3.

Over 90 per cent of the fuels tested have an amount of volatile matter which is between the limits of 18 and 48 per cent of the combustible. Within this range the points are seen to lie remarkably close to the curve. The use of the curves for the determination of the hydrogen in the volatile matter would have given less than two per cent maximum error within that range, or about 0.5 per cent in the determination of the amount of hydrogen in the combustible. As the points represent tests of over 200 different coals, the curve can be used with confidence for all semi-bituminous or bituminous coals occurring in the United States.

Above the limit of 48 per cent of volatile matter in the combustible lie some of the lignites and the peats. There is rather more average variation here, though the maximum error again by the use of the curve would not be more than two per cent in terms of the volatile matter, or a possibility of about one per cent error in the determination of the percentage of the hydrogen in the combustible.

Below 18 per cent volatile matter are the semi-anthracites and anthracites; the possibility of error in determining, from the curve, the hydrogen in the combustible is only one-quarter to one-half of one per cent. Of all the coals tested there is only one which has a hydrogen content differing considerably from that given by the curve: that was a coal with only about 6 per cent of volatile matter and which is described as an anthracite-graphite coal mined in Rhode Island. If the curves of Figs. 2 and 3 had been used for determining the hydrogen content of the dry coal, the results obtained would have differed from

the analyses less than two-tenths of one per cent in 90 per cent of the coals; and for one coal only would the difference have been greater than 1 per cent. One per cent error in the determination of the hydrogen will cause an error of about 100 B.T.U. in the latent heat of the steam formed by burning one

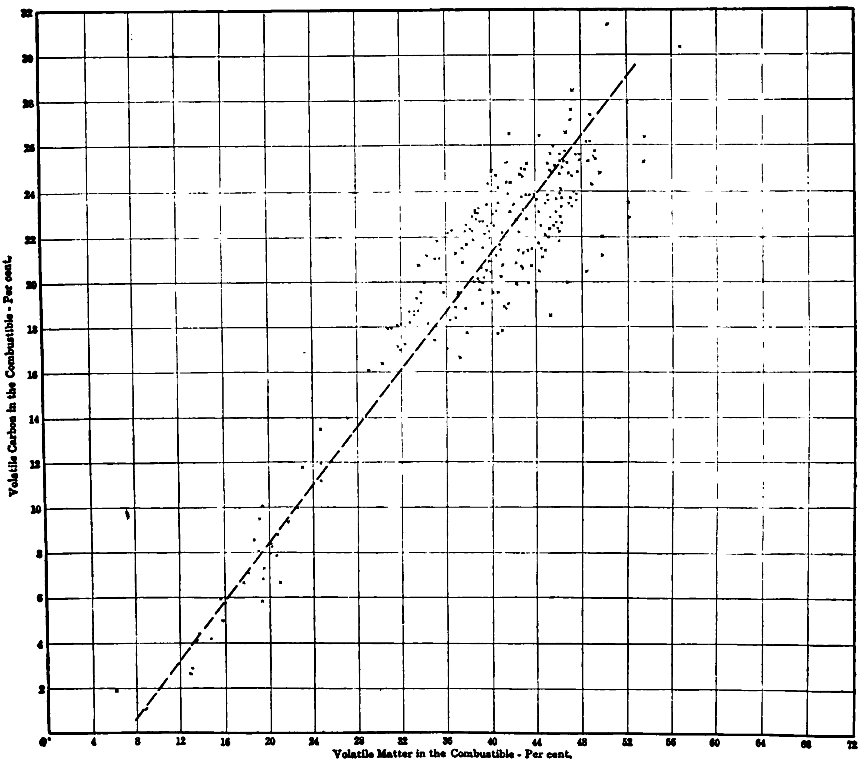



FIG. 4. SHOWING THE VOLATILE CARBON AS A PERCENTAGE OF THE TOTAL COMBUSTIBLE MATTER IN COAL

pound of combustible, or about seven-tenths of 1 per cent error in the calculation of the lower heat value of the coal. This is the limit of error by the use of these curves. The probability of error for fuels which are neither extremely high nor extremely low in combustible matter is not more than one-tenth of 1 per cent.

The accompanying table is taken from the curves in Figs. 2 and 3:

| Per cent of Volatile Matter in the Combustible. | Per cent of Hydrogen in the Volatile Matter. | Per cent of Hydrogen in the Combustible. |
|---|---|---|
| 10 | 37.6 | 3.8 |
| 12 | 33.4 | 4.0 |
| 14 | 29.9 | 4.2 |
| 16 | 27.2 | 4.35 |
| 18 | 25.0 | 4.50 |
| 20 | 23.2 | 4.65 |
| 22 | 21.7 | 4.78 |
| 24 | 20.4 | 4.9 |
| 26 | 19.2 | 4.98 |
| 28 | 18.1 | 5.05 |
| 30 | 17.1 | 5.13 |
| 32 | 16.2 | 5.17 |
| 34 | 15.4 | 5.22 |
| 36 | 14.7 | 5.27 |
| 38 | 14.0 | 5.32 |
| 40 | 13.4 | 5.36 |
| 42 | 12.9 | 5.38 |
| 44 | 12.3 | 5.40 |
| 46 | 11.8 | 5.42 |
| 48 | 11.3 | 5.44 |
| 50 | 10.9 | 5.45 |
| 52 | 10.5 | 5.46 |
| 54 | 10.2 | 5.47 |
| 56 | 9.8 | 5.48 |
| 58 | 9.5 | 5.50 |
| 60 | 9.2 | 5.52 |
| 62 | 8.9 | 5.53 |
| 64 | 8.6 | 5.54 |
| 66 | 8.4 | 5.56 |
| 68 | 8.2 | 5.58 |
| 70 | 8.0 | 5.60 |

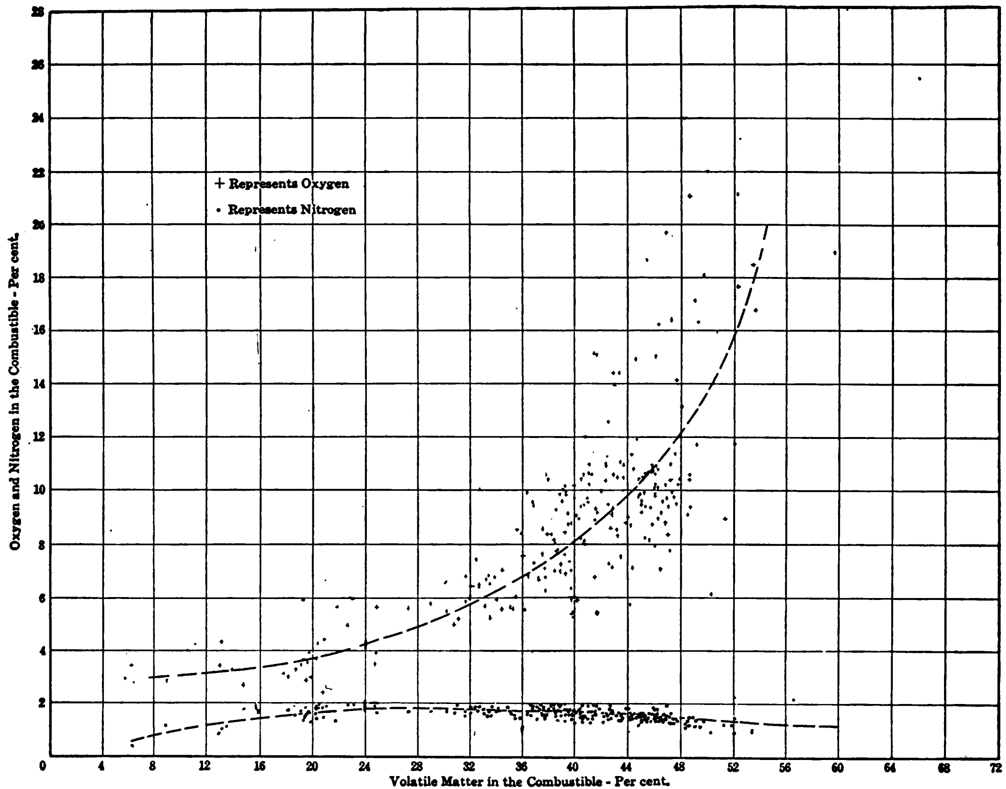



FIG. 5. SHOWING THE OXYGEN AND NITROGEN AS PERCENTAGES OF THE TOTAL COMBUSTIBLE MATTER IN COAL

In a similar way there may possibly be some relation between the Carbon, the Nitrogen and the Oxygen in the volatile matter and the amount of that volatile matter. To investigate the carbon, Fig. 4 has been plotted. It will be seen on inspection that although there is some relation between the amount of volatile carbon and the total amount of volatile matter, this relation is not constant enough to be of value. If the relation between the volatile carbon and the total volatile matter were assumed to be that represented by the dotted line, it would lead to errors in the determination of the total carbon which in several cases would be as great as 6 per cent.

The oxygen and nitrogen contents of the combustible are shown in Fig. 5. The oxygen is extremely variable; thus a coal with 49 per cent volatile matter in the combustible is seen to contain an amount of oxygen which varies from 6 per cent to 22 per cent. The nitrogen is very constant in amount; it is between the limits of one and two per cent for over 95 per cent of the coals tested, and its amount can be taken from the dotted curve with but slight error.

It appears from the foregoing that the hydrogen in a fuel can be found with sufficient accuracy for the engineer's purposes by a proximate analysis; but that the total carbon, that is, the sum of the fixed carbon and the volatile carbon, cannot be so determined. Fortunately a method presents itself for the experimental determination of the total carbon without carrying out the usual slow combustion, — a method moreover which can be entrusted to the engineer. After the calorific value of the fuel has been found in the bomb calorimeter, there remain imprisoned in the bomb the products of the combustion. The carbon of the fuel is all burned to $CO_2$. If the products of combustion are permitted to escape slowly from the bomb and made to pass through a solution which absorbs only the $CO_2$, the increase in the weight of the solution will be the weight of the $CO_2$ formed by the combustion, and the weight of the carbon that was burned can be immediately calculated. The apparatus for accomplishing this is shown in Fig. 6. The bomb to serve this purpose is provided with two outlets controlled by needle valves A and H, instead of the usual single outlet. One outlet

connects with the large bottle B, which is initially nearly full of water. The water in B is displaced into a similar bottle C when the pressure in B increases. From B, glass tubing leads to the drying tubes D and F, containing concentrated sulphuric acid, and to the Geissler potash bulb E, containing potash solution in one part and granulated soda-lime in the other. There is a cock at G. For the determination of the total carbon, the bomb, after the explosion is complete, is connected as shown and the valve at A is opened slightly, the cock G being closed. The products of combustion which are at a high pressure enter B, displacing the water, and when B is nearly full of the gas

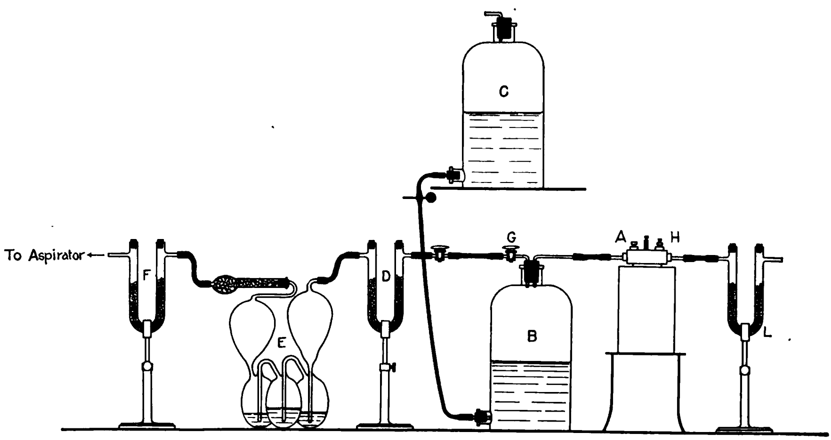



Fig. 6

APPARATUS FOR DETERMINING THE TOTAL CARBON IN COAL

the valve A is closed, the aspirator is set in operation, and the cock G adjusted so that the gas passes through the potash solution at the rate of about two bubbles per second. When nearly all the gas has been drawn out of B, the valve A is again opened and B is refilled. This is repeated until the pressure in the bomb is reduced to below atmospheric pressure; that is, until with valve A open and with the pinch cock on the rubber tubing connecting B and C closed, the aspirator can draw no more gas through E. The water is then allowed to rise in B till it nearly fills it. There remains to be sent through the absorbing tubes only the gas in the bomb; to effect this the valve H is

opened slightly and air is drawn through by the action of the aspirator. A liquid seal L prevents the diffusion of any of the products of combustion through H. After the air has been going through for half an hour the amount of $CO_2$ remaining unabsorbed is negligable. The bulb E is weighed both before and after the passage of the gases; its increase in weight is the weight of $CO_2$ formed by the combustion. The function of the tube D is to dry the gases before they reach E so that no moisture may be absorbed there; tube F prevents moisture reaching E from the aspirator side.

It might be supposed that the hydrogen content of the fuel could be determined at the same time (with a somewhat modified arrangement of the apparatus) by absorbing and weighing the $H_2O$ resulting from the combustion of the hydrogen. Unfortunately this cannot be done on account of the sulphur which is always present in coal. The sulphur forms $H_2SO_4$ in the bomb and this substance has a great affinity for $H_2O$. Even if considerable heating of the bomb is resorted to, some of the $H_2O$ will remain held by the $H_2SO_4$, and consequently the amount absorbed in the drying tubes will be less than the total quantity formed by the combustion.

The sulphur in coal can also be determined from a bomb calorimeter test avoiding the more troublesome Eschka method. To accomplish this, a few grams of water are put in the bomb before making the combustion, and then after the combustion the bomb is washed out eight to twelve times, using about 25 cc. of water each time. The washings are acidified with hydrochloric acid, and the sulphur precipitated by barium chloride and weighed as barium sulphate. The two methods of determining the sulphur give results which agree very satisfactorily.

*Summary.* The analysis of coal may be either " proximate " or " ultimate." The former suffices for ordinary purposes; the latter is necessary for certain calculations of heat losses and efficiencies and for other purposes. A close approximation to the ultimate analysis can be obtained (avoiding the troublesome and costly process of actually making the analysis) by determining the hydrogen and nitrogen from the proximate analysis; the carbon and sulphur from the products of combustion remaining in the bomb calorimeter; and the oxygen by difference.

## WATER POWER AND IRRIGATION IN SOUTHWESTERN COLORADO

BY F. PARKMAN COFFIN, S.B., 1903

The San Juan mining district is located among the high mountains of Southwestern Colorado. The principal products of the mines are silver and gold, while copper, lead and zinc are produced in lesser quantities. Narrow guage railways tap the region from three sides, following up the deep valleys of the rivers whose watersheds are separated by mountain barriers. The mines are located high up on the mountain sides, thousands of feet above the railways, at elevations of from 10,000 to 12,000 feet. Many of the mills are also remote from the railways.

All fuel and supplies, after long railway hauls, must be packed on the backs of mules or laboriously hauled up mountain roads by four-horse and six-horse teams. Power generation at the mines is out of the question, owing to the cost of hauling fuel, and the very existence of the mining industry in this region is dependent upon electric transmission from water power developments down in the canyons thousands of feet below the mines.

The three rivers on whose watersheds the district lies, are: the San Miguel, on the west in the county of that name; on the north the Uncompagre, in the county of Ouray; and on the south the Animas, in the county of San Juan. The entire region is a lofty plateau, in which deep valleys have been eroded by glacial action, leaving hundreds of mountain peaks from twelve to fourteen thousand feet and more in elevation. On account of its altitude, as well as its situation, being upon the windward side of the Rocky Mountains, this plateau receives a greater rainfall than other parts of the state. This provides an adequate water supply for power generation, provided that storage reservoirs are used. These are essential in the winter when all running streams are frozen solid. In the summer, the rivers are fed largely by melting snow on the mountains.

The hydro-electric developments all have high heads and operate with impulse wheels under pressures varying from 500 to 1500 feet. The Telluride Power Company, with four stations, covers San Miguel and Ouray counties with a network of transmission lines, while the Animas Power and Water Company supplies San Juan County from a station in La Plata County. The latter system has been running only a few years, but has built up the industry in its territory rapidly.

The Telluride Power Company has an interesting history, being the pioneer company in the field of alternating current power transmission. The enterprise began in connection with an unprofitable mine.* "The Gold King" mill, situated at an altitude of 12,000 feet, where the cost of fuel for steam power had become prohibitive, was the first to be operated by means of this power. This property had been attached in 1888 to satisfy a continued deficit in operation, due to the excessive cost of power, whereas a handsome profit would have been realized had power been secured at not to exceed a hundred dollars per horse-power-year.

"Down in a deep gorge of the valley, over 2,000 feet lower, but less than three miles away, two mountain streams formed at their confluence the South Fork of the San Miguel River, offering cheap and continuous power. A stay of proceedings was secured; and as a means of transmitting this power, cable drive, compressed air and continuous-current electricity were successively investigated. The limitations of each were apparent, while the advantages of alternating current and higher pressure became gradually recognized, and a decision was reached to attempt their use. . . .

"A generator and a motor for 3,000 volts and of 100 h.p. each were ready for trial in the fall of 1890. Difficulties caused by ice at 40° below zero, by speed control over unusually high water pressure, by avalanche, by blizzard, by electric storms unknown in low altitudes, and scores of other difficulties now generally forgotten but then most serious, marked every step of progress. Notwithstanding all of these, unqualified success from the beginning caused gradual and constant growth,

*P. N. Nunn, in *Cassiers Magazine*, January, 1905.

until at the present time (1904) The Telluride Company and its allied industries have six power stations and nearly a thousand miles of line in Colorado, Utah and Montana."

Synchronous motors were employed until 1896, three hundred horse-power being the largest used. The system, however, grew more complicated and difficult to control with the addition

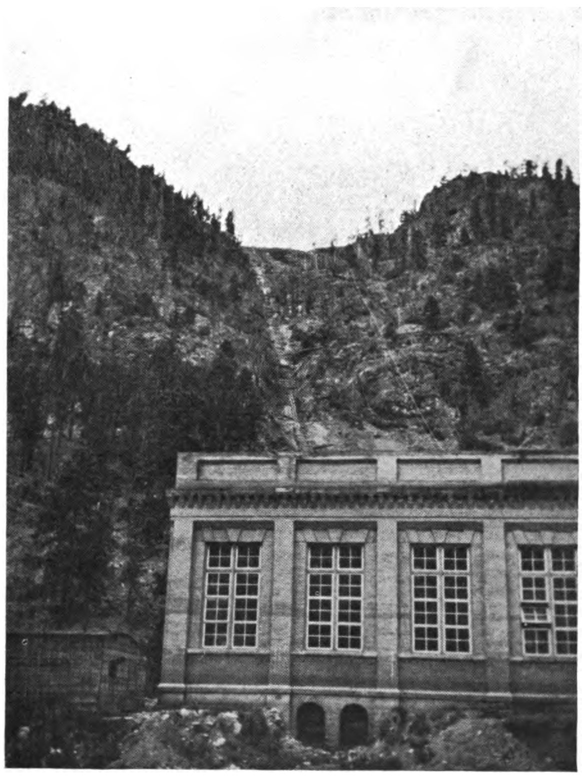


FIG. 1. ANIMAS POWER STATION, WITH PIPE LINE IN BACKGROUND

of each new synchronous motor, with its starting motor to cause disturbances. Instruments were lacking and the effects of power-factor were not appreciated. So with the development of the induction motor, the old motors were replaced.

There are now two power stations on the site of the original one at Ames. The older station operates under a head of 600

feet and contains two 600 kilowatt alternators of the revolving armature type direct-connected to Pelton wheels. The new station contains one revolving field alternator of about 3,000 kilowatts capacity, direct-connected to a Pelton wheel operating under a head of 1,000 feet. The pressure pipe is fed by a flume two and a half miles long, which brings water from a chain of three reservoirs located at elevations of 9,800, 10,000, and 11,900 feet, respectively. The last one, Lake Hope, was tapped by a tunnel piercing a ridge of the mountain and entering the bottom of the lake, 60 feet below the surface. This tunnel was drilled from the outer end, and then blasted through into the lake.

The third station is located at Ilium, five miles below Ames, on the South Fork of the San Miguel. A wooden flume conducts the water along the steep wall of the canyon for five miles, then a pipe drops 500 feet to the Pelton wheel coupled to a 1200 kilowatt revolving field alternator. These three stations operate in parallel, the transmission being at 11,000 volts and 60 cycles, three-phase. The system is controlled from the Ilium station by manual regulation of voltage and speed. The speed is controlled, first, by deflecting the jet, and then slowly adjusting the needle by means of a governor relay, which is operated by manually controlling the pilot valve. The equipment of the older station is of Westinghouse make, as were all the original machines; the two newer ones, however, have General Electric machines.

A fourth station is located in the town of Ouray, on the Uncompagre River, and operates under a head of 600 feet. Almost every mine and mill in Ouray and San Miguel counties draws power from this system, also the towns of Telluride and Ouray, with a population of 3,000 each. Two or three mines, however, have water powers of their own.

The Smuggler Union Mine near Telluride has an interesting development of 1,000 kilowatts capacity, in that a total head of 3,000 feet is developed in two stages, the upper station being located on the brink of a cliff 1,400 feet above the valley. The armature of the generator had to be hauled up a narrow, zigzag road on a twelve-horse team, with six horses ahead and six behind.

Over the range in San Juan County, where Silverton is the center of a more recently developed mining district, is the watershed of the Animas River (Rio de los Animas de Perdidos, or River of the Lost Souls). This territory is supplied by the lines of the Animas Power and Water Company from their station in the Animas canyon, some 25 miles south of Silverton. Two lines, operating at 43,000 volts, transmit the power to a sub-station near Silverton, where it is reduced to 17,000 volts for distribution over 60 miles of lines to the numerous mines.

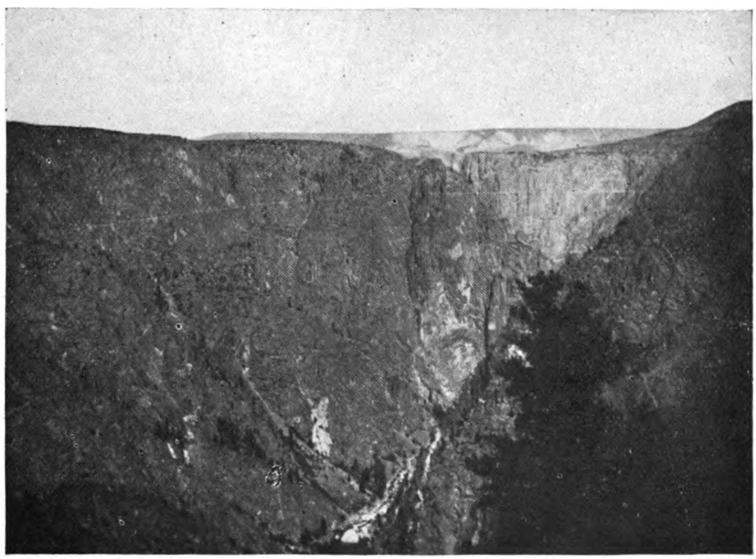


FIG. 2. BLACK CANYON OF THE GUNNISON

One 43,000 volt line runs through the bottom of the canyon, where it is more sheltered from lightning disturbances, the other stays on higher ground outside the canyon, and is located where it will not be disturbed by snow-slides in winter; so one line or the other is sheltered from the elements at any season of the year.

The power station receives water from Cacade Creek, a tributary of the Animas, which is diverted through three miles of flume and channel into a large reservoir a thousand feet above the Animas River. A rock fill dam, sixty feet high,

allows of drawing down the lake by that amount. From the foot of the dam a wooden flume carries the water for two miles to a small regulating reservoir on the brink of the canyon. From this the pipe line drops 900 feet to the station beside the river. Here a substantial masonry building contains two General Electric alternators of 2,250 kilowatts each, and 60 cycles, driven by impulse wheels. The voltage is controlled by a Tirrill regulator, and governing is accomplished by automatic control of the deflector with occasional hand adjustment of the needle in the nozzle to economise water. The deflector is located just in front of the nozzle. It is a steel ring mounted on trunnions and surrounds the jet, which is smaller than the bore of the ring. By tilting forward, the upper lip deflects the jet downwardly and away from the wheel.

This device replaced a synchronous by-pass consisting of a second nozzle whose needle was linked to one end of a lever, the other end being linked to the needle of the operating nozzle. As first installed, the pipe line was butt-jointed with bolted flanges, and was laid partly upon loose "slide-rock." After a few months' operation, water hammer caused by a sudden closing of the needle, with a non-synchronous opening of the by-pass, burst the pipe, shutting down the station for six months. The sudden rush of water from the broken pipe carried down all loose slide-rock in its path and excavated a trench to bedrock in which the pipe could be relaid. The flanged joints were replaced with riveted butt-straps, which allowed of laying the pipe on the rock and following its contours, thus making it very secure.

Another serious source of trouble on this system was lightning disturbances, which caused frequent shut-downs. This part of Colorado is visited by the most frequent and severe electrical storms to be found in the United States. They are of almost daily occurrence from June to August.

About 98 per cent of these shut-downs were caused by the breaking down of transformer brushings where discharges jumped across.

During the lightning season of 1907, the number of storms was 34; storms causing complete shut-downs, 8; storms causing partial shut-downs, 17; storms causing no shut-downs, 9. In other words, partial or complete shut-downs were caused by 73

per cent of the storms. The arrester equipment then consisted of multigap arresters only, and there was no evidence that they were taking any discharges. Many of these were installed at the customers' premises.

For the next season a group of aluminium cell arresters was installed at the sub-station by the General Electric Company,

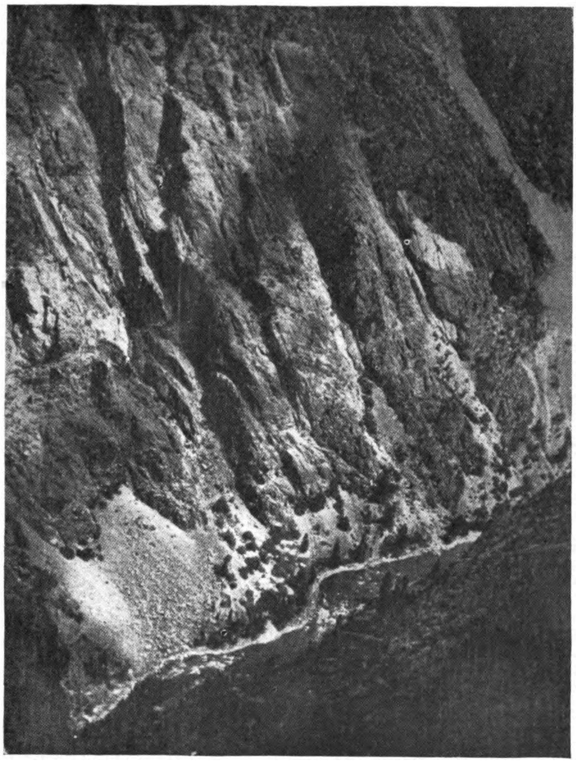


FIG. 3. THE BLACK CANYON OF THE GUNNISON FROM ABOVE

together with a number of the electrolytic (or "liquid electrode") type at the sub-station and generating station. The new arresters were so successful that only one shut-down occurred during the lightning season in 1908, and this was due to lack of arresters at certain points, rather than to the failure of those installed. Storms were frequent, there being 24 during July

and 20 in August. Telltale gaps used to keep a record of discharges, showed that the arresters were operating every storm.

Just north of these mountains the valley of the Uncompagre River broadens until the river flows through a desert plain from five to ten miles wide, flanked by arid mesas on either side. The soil is mostly adobe, and formerly grew nothing but sagebrush. Irrigation, however, has worked wonders with it when water could be obtained. Many thriving farms are now to be seen irrigated with water from the Uncompagre River. But in a dry season this stream will barely furnish water to irrigate 20,000 acres out of a total of 160,000 acres of arable land below ditch levels.

A few miles to the north, the Uncompagre River flows into the Gunnison, the second largest river in Colorado, which flows out into the valley from a deep canyon, which it has cut for 50 miles through the mesa. For the last 25 miles this canyon runs parallel with the Uncompagre valley and only five or six miles to the eastward. It is 3,000 feet deep, cut through solid granite, with walls varying from 60 degrees slope to perpendicular cliffs.

This river is to be diverted to water the valley of the Uncompagre by a tunnel six miles long now being driven through the Vernal Mesa by the U. S. Reclamation Service. Work is progressing from both ends, there being but one mile left between the headings last September.

The tunnel passes through granite for all but the last mile, where shale and then adobe clay are met at the outlet. The grade is 10 feet to the mile and this has served to drain off by gravity all water encountered at the lower heading. This end has been the easier proposition of the two, but formidable difficulties have been encountered at both ends of the work. A creek flows over the lower end of the tunnel and passes within two hundrd yards of the lower portal. Last summer a cloudburst occurred on the watershed of this creek which, accordingly, overflowed its banks and proceeded to cut new channels in the soft adobe soil. One of these cut down into the tunnel just back of the portal where only a timber lining held the walls, filling the tunnel with mud and water for 2,000 feet in, and driving out

the working force through a shaft a mile back. Over a month was required for cleaning up.

The river portal is located at the foot of a gulch which slopes into the canyon just gradually enough to allow of building a zigzag road from the top of the mesa down to the river. It is the only place where this could have been done, or where room could be found for a construction camp at the bottom of the canyon. At this end the builders are not favored by the grade of the tunnel, and all water encountered must be pumped. Several electrically-driven pumps are located near the heading and receive current from the power station at the camp in the bottom of the canyon. All coal is hauled over the mesa and down into the canyon by four-mule teams, five or six teams making the trip every day. At one time such quantities of water were encountered at the upper heading that the work had to stop for several months to make the necessary provision for handling it.

The tunnel was begun by a contractor who failed. Since then the work has been carried on by the engineers of the Reclamation Service with a government force. A mistake was made at the beginning in not providing a suitable power supply for the work to avoid the costly hauling of coal. A permanent hydro-electric development on the Gunnison River above the portal could later have supplied Montrose and other towns in the valley. Or a steam station could have been installed at Montrose, where coal can be cheaply hauled from the mines at Grand Junction over a broad guage railroad. When the government took over the work, however, it was considered too late for a change to be made.

The unforeseen difficulties encountered are expected to increase the cost of the project from the original estimate of $25 per acre to about $35 per acre, which represents the cost of the water rights which the farmers must repay to the government in ten annual instalments after the delivery of water upon the lands. After this, the works belong to the farmers and are managed by a Water Users' Association. This cost, however, will not be excessive in comparison with other projects; and the benefits which the existence of this agricultural community will bring to a part of the country now chiefly dependent upon the mining industry, will be widespread.

## A BRIEF DESCRIPTION OF THE CAMBRIDGE WATER WORKS

### History

The story of the public water supply may well begin with the incorporation of the "Cambridge Aqueduct Company," which was chartered April 13, 1837, with an authorized capital of $30,000. The company was empowered to take water from land and springs at or near Prospect Hill in Charlestown (now Somerville), and to lap pipes and aqueducts, etc., to and through Cambridge. This was done, and quite an extensive system of pipes made of hollow logs were laid in Cambridge streets, chiefly in what was called the "lower Port," comprising the section east of about Windsor Street. I have a section of the pipe taken from the ground at the corner of Portland and Main streets, the wood being perfectly sound. There are now living at least two men who distinctly remember drinking water from taps taken from these hollow logs.

The necessity for a more extended supply must have soon become apparent, for in 1852 a private corporation, called the "Cambridge Water Works," was incorporated — but no water supply was mentioned. In 1856 the company was authorized to take water from Fresh Pond and distribute it to the inhabitants of Cambridge. The works were constructed the following year, 1857. In 1861 the Cambridge Water Works were authorized to buy out the Cambridge Aqueduct Company, and all its rights and privileges, which was done.

April 25, 1865, an act of the legislature was passed, authorizing the city of Cambridge to purchase all the property and rights of the Cambridge Water Works and undertake the business of supplying the inhabitants of the city with water. This the city by popular vote decided to do, and the purchase was made for the sum of $291,400.

Ten years later (1875) the city secured the right to take the waters of Spy and Little ponds and Wellington Brook as an additional supply, as the water in Fresh Pond had been pumped

PAYSON PARK RESERVOIR, 40-INCH STEEL PIPE. (Crossing on B. & M. R. R.)

to an extremely low point in previous years, due to the rapid increase in the consumption by the city. Certain work was done under this right, but little water was ever used from this source. It seemed imperative that a new and better supply should be secured. An attempt was made to get the right to take water from the Shawsheen River, but this was refused. After a long and persistent contest in the legislature, the right to take water from Stony Brook in Waltham and adjacent towns was secured in 1884. The work of building the dam and reservoir and laying the pipe conduit to bring the water from the reservoir to Fresh Pond was at once begun, and November 5, 1887, the new works were dedicated and put in service. The total cost of the works to this time was $2,436,496.50.

It was thought that now the supply would be sufficient for many years, but the extremely dry years of 1893 and 1894, with the increase in consumption, forced the city to again consider the extension of the works or a union with the Metropolitan Water System, then just being started.

After prolonged discussion it was decided to maintain an independent supply and extend the works. What was needed was increased storage capacity, increased head or pressure in the pipes, and a new pumping engine. A large storage reservoir or basin was built in Lincoln and Lexington, called the "Hobbs Brook Basin." A new distributing reservoir was built on the high ground of Payson Park in Belmont, and a new pumping engine, of ten million gallons daily capacity, established at the pumping station on the shore of Fresh Pond, together with a new forty-inch force main pipe from the engine house to Payson Park Reservoir, and a leading main from the reservoir to near Harvard Square, to connect with the distributing system, a total length of about four miles of steel pipe, forty inches in diameter. This work was carried out in the years 1895, 1896, and 1897. The total cost of the works to November 30, 1897, was $5,285,926.11.

In 1904 it became apparent that the pipe conduit bringing the water from the Stony Brook Reservoir to Fresh Pond was delivering less and less water, and so seriously crippling the works. It was therefore decided to replace portions of this

PAYSON PARK RESERVOIR, 40-INCH PIPE. (Curves near Reservoir)

cast-iron pipe with a conduit of concrete construction 63 inches in diameter. In 1905 and 1906, 27,335.35 feet, or 5.177 miles, of this conduit were constructed from Fresh Pond to the city of Waltham, and was the last work of magnitude undertaken in the Cambridge Water Works extension. The total cost of the works to November 30, 1906, was $6,342,200.46.

Such is a very brief outline story of the Cambridge Water Works on its historical side. Let us now glance at a few of the interesting features of the works from an engineering standpoint.

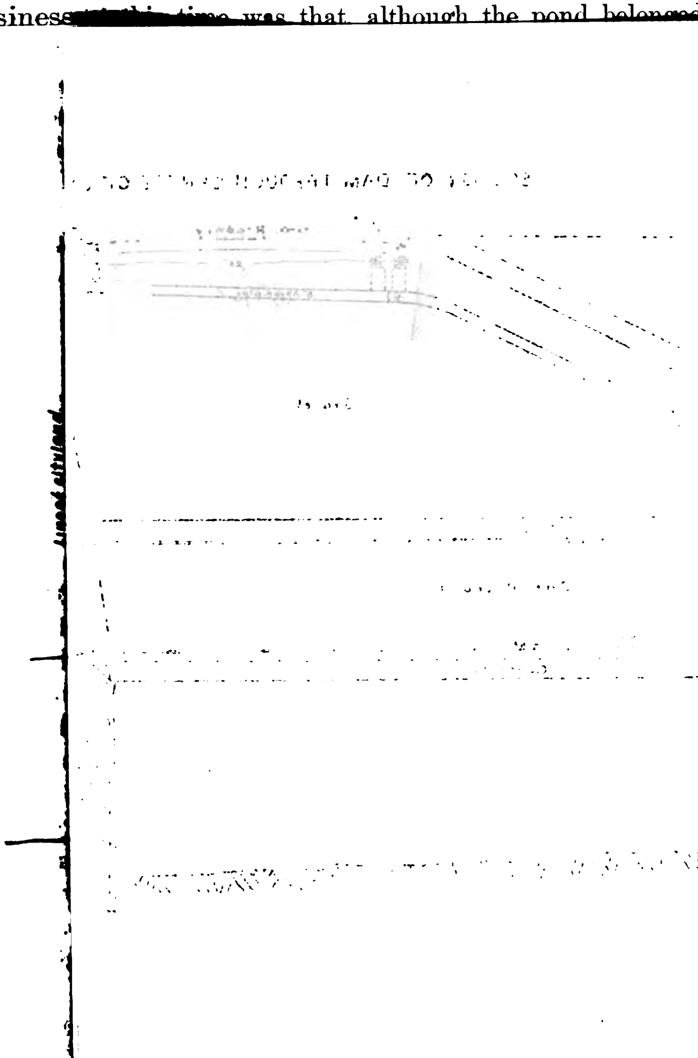
### Fresh Pond

This pond has always been an important feature of the works. For many years it was the only source of supply the city had. The drainage area is small, and in proportion to the area the yield has been quite large. The water is fairly pure and agreeable, but somewhat hard. Two curious and interesting facts about the pond are worth referring to, viz., its low elevation and its physical or geologic location. The water in the pond when it is full is only about one foot above the level of mean high tide in the Boston Harbor and Mystic River, into which its outlet, Alewife Brook, discharges, so that at many times of spring or high tide the surface of the water in the pond is actually *below the level of the sea.* The pond in places is fifty feet deep, so that the most of the body of water in the pond is greatly below sea level. Originally the sea water flowed into Fresh Pond at times of high tide, but for many years this has been prevented by gates.

The pond seems to have been formed in a great bed or strata of clay. Excavations and borings show clay on nearly all sides, overlaid in some portions with glacial drift or gravel. It is rather curious that in this large area forming the "Fresh Pond meadows," so-called, of this impervious material, such a deep, low-lying depression should exist.

For many years ice cutting was carried on upon this pond. I am informed that the first ice shipped to the south in vessels was cut here by the first Mr. Frederick Tudor, who, and his descendants, carried on for many years the ice business on a very large scale. At one time there were said to be sixteen ice

houses on the border of the pond. A curious fact about the ice busines… time was that although the pond belonged to



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houses on the border of the pond. A curious fact about the ice business at this time was that, although the pond belonged to the state, — being a "great pond" under Colonial law, — *i. e.*, contained more than fifteen acres, — yet the owners of abutting lands on the pond, by a solemn agreement, divided up the pond into "ice rights," showing these "rights" on a plan recorded and called the "pie plan." The entire shore of the pond is now owned by the city of Cambridge, and all the ice-houses have been torn down and the entire ice business, once so flourishing and lucrative, has been removed elsewhere.

## Stony Brook Extension

The main features of this work were the taking of the land and construction of a reservoir of about 350,000,000 gallons storage capacity and 71.7 acres surface area, — the construction of an earthern dam with masonry core wall, gatehouse, etc., and an iron pipe conduit connecting the reservoir with Fresh Pond, about 39,330 feet in length. This pipe was of two sizes, about 5,010 feet being 36 inches in diameter, the remainder being 30 inches in diameter. Some interesting points developed about this pipe after it had been in service awhile. The first was that the pipe did not deliver as much water as it did at first. It was found that the pipe was so laid that a considerable length of it was laid above the hydraulic grade line, — at one point about 28 feet. This, of course, caused a negative pressure, or tendency to vacuum on the pipe in the high section. The pipe not being airtight permitted air to collect in a short time, and so greatly reduced the capacity of the pipe. Exhaustion of the air remedied this trouble, but it quickly gathered again and was as bad as before. This was a source of great annoyance and trouble, and was never remedied until the new conduit was constructed as described later. This pipe line was put in service in 1887. In 1894 I made a series of measurements of the flow of water in the pipe by means of a current meter placed in the larger end (36-inch), at the gatehouse at the dam. This was particularly interesting, as it was an attempt to measure the actual velocity in a compound pipe of rather large diameters

and unusual lengths. The quantity flowing in the pipes as recorded by the meter was 8,066,800 gallons per twenty-four hours.

Computed by the formula given by Mr. E. Sherman Gould, in his little book, "Practical Hydraulic Formulæ," with coefficient for rough pipe, the flow should be 8,406,700 gallons per twenty-four hours, and by the Howard Murphy formula (see Trautwine Civil Engineers' Handbook), the flow should be 8,865,500 gallons (see *Journal New England Water Works Association,* vol. viii, No. 4). Incrustation and increase in the amount of air retained in the pipe later reduced still further the flow to but little over 7,000,000 gallons.

These works on Stony Brook were scarcely completed before the city was involved in a series of suits for damages for loss of water power at various mills on the brook and also on Charles River below its junction with Stony Brook. Six mill powers were claimed to be affected, three on the brook itself and three on the river. The three first cases were complicated by land and building and machinery taken or affected. The three on the river were for the loss of water power solely and are therefore most interesting.

The area of the watershed of Stony Brook is about 23 square miles and the total drainage area of Charles River is 251.42 square miles. But a curious fact was discovered in relation to this drainage area. The course of Charles River is very crooked, and, in passing through the town of Dedham, it passes quite near the Neponset River, and at a slightly higher elevation. In early Colonial days (1639) a ditch, or canal, called "Mother Brook," was dug connecting the two rivers, taking water from the larger Charles River to increase the supply in Neponset River. This went on for nearly two hundred years, causing much friction and litigation among the mill owners as to their respective rights. In 1831 it was decided that one-third of the natural flow in Charles River should be allowed to flow into Neponset River. This would reduce the actual drainage area by one-third of the area above its junction with Mother Brook, or 66.64 square miles. The total drainage area of Charles River above the dam in Waltham is 251.42 square

miles, this, reduced by the 66.64 square miles diverted into Neponset River, leaves 184.78 square miles. Now, then, the question was simply how much the diversion of the water from an area of 23 square miles would reduce the quantity of water available for power from an area of 184.78 square miles. The mill owners claimed a total loss of all the water from the 23 square miles which, passed over the three dams, would yield them 200 horse-power per day, a horse-power they claimed to be worth $800, which would make the total valuation $160,000 as their loss. The city's defense was that but little loss of power was occasioned by the taking of such water as the city could use, for the reason that the ratio of the amount of water from Stony Brook to the amount in Charles River was so small that when any considerable quantity was flowing in Stony Brook, vast quantities were being wasted over the dams on Charles River, and when the flows in the river were small so that practically all the water could be used for power, the amount flowing in Stony Brook was very small. A careful computation made the loss about fifteen horse-power. The commissioners before whom the case was tried awarded a lump sum of $15,000, which was accepted by both parties! (See *Journal New England Water Works Association*, vol. vii, No. 4, 1893.)

## Hobbs Brook Extension

Of the four items of work involved in this extension, the largest and most expensive was the Hobbs Brook Reservoir. Nearly a thousand acres of land was taken for the purpose, the water surface of the reservoir being 560 acres and the total storage capacity of about two and one-half billion gallons. The entire surface of the land flowed was stripped clean of loam and mud and the shallow flowage reduced by filling the shores with the excavated material, covered with gravel, and much of it protected with stone rip rap. Immense quantities of fine loam were banked and buried in this way, at the same time the Park Department were buying great quantities at good prices for inferior loam. While it seemed so desirable to furnish the loam to the Park Department, the matter of transportation was found to be so difficult and expensive as to be prohibitive.

The dam is of earth, with a concrete core wall cornice down to bed rock, about twenty-five feet below the bed of the valley. No good place was found for a suitable spill or waste way, so a large gate, or spillway house, was built at the upstream side of the dam, with large weirs on three sides, with suitable flash boards discharging into a large waste conduit passing through the dam and core wall, somewhat in the English practice. There is also provided an auxiliary waste way on one side for emergency use only.

The distributing reservoir at Payson Park occupies about eleven and a half acres in the town of Belmont. It has a capacity of about forty-three million gallons, built in two compartments with a concrete lining.

In connection with the construction of this reservoir a very interesting and at the same time difficult question arose, and in order to understand it a few figures will be necessary. The elevation of high water in Fresh Pond above the city base is 16.85, the elevation of water in the Stony Brook Reservoir is 81.00, the elevation of water in Hobbs Brook Reservoir is 181.00. The elevation of the water in Payson Park Reservoir was to be 178.50, or nearly the same as Hobbs Brook Reservoir. The water from this Hobbs Brook Reservoir, then, was to be allowed to run by gravity from elevation 181.00 to elevation 16.85, and from there it was to be pumped to elevation 178.50 again. This, of course, did not seem like good engineering, and the proposition was made to dispense with the construction of Payson Park Reservoir and connect Hobbs Brook Reservoir with the pumping engines and the distribution system direct. Then, as long as the supply lasted, — which would be about six months, — the pressure could be maintained from Hobbs Brook direct without pumping, thus saving a large amount of coal. When pumping was necessary the engines could pump against the head of the Hobbs Bank Reservoir, from the supply derived from Fresh Pond and Stony Brook. This proposition looked attractive, and was thoroughly investigated, when it was found that the desirable and undesirable features of the plan were very closely balanced. After a very close examination it was finally decided to carry out the work as originally planned for the following principal reasons:

(*a*) Little or no difference in cost was shown by either plan when all the factors were considered.

(*b*) The first plan gave a better and more elastic control of the water supply. The water taken from Hobbs Brook was a different quality from that taken from Fresh Pond. By the first plan a mixed water was given the year round, by the second plan part of the year one quality was given, and part of the year another was given. If at any time Hobbs Brook Reservoir became contaminated (as with typhoid germs, etc.), it could be more readily separated by the first than by the second plan.

(*c*) The pipe connecting the reservoir with Fresh Pond would have been a long one, — about eleven miles, — and it was found that, unless the pipe was made of very large dimensions a serious loss of head would occur in the piping system. This matter is referred to here as showing what troublesome and difficult questions often arise in the course of an engineer's practice, questions which require the exercise of the utmost of his common sense and good judgment.

The pipe line connecting Payson Park Reservoir with the pumping station and the piping system is about 20,000 feet in length, and the question of *material* was an important one, as it intimately affected the cost. After investigation it was decided to use riveted steel plates for the pipe, which was 40 inches in interior diameter. Theses plates were $\frac{3}{8}$-inch in thickness, and were coated with a protective coating, to prevent corrosion, made of asphalt, linseed oil, and resin, which was baked into the pipe, forming a kind of japan or enamel. The steel plates were 7 feet wide, and four plates were riveted together, making a section 28 feet long, which was coated and delivered on the work ready for laying.

At one place the pipe crossed over a railroad track, making a span about 94 feet long. Here the thickness of the plates were increased and heavy angle irons were riveted on the top and bottom of the pipe, and so the pipe was made to be self-sustaining for this span. As this pipe was exposed to the extremes of heat and cold, a slip joint was provided at one end of the span. Although the pipe is filled with flowing water, a movement of

just half an inch has been recorded at the slip joint. (For a discussion of "Use of Steel for Water Mains," see *Journal New England Water Works Association*, vol. viii, No. 4.)

The new twenty million gallon pumping engine at Fresh Pond was designed by E. D. Leavitt, of this city, and is as fine a piece of workmanship as can be found in this vicinity, and to one who is interested in fine machinery is well worthy a visit. The engine and boilers cost nearly $200,000.

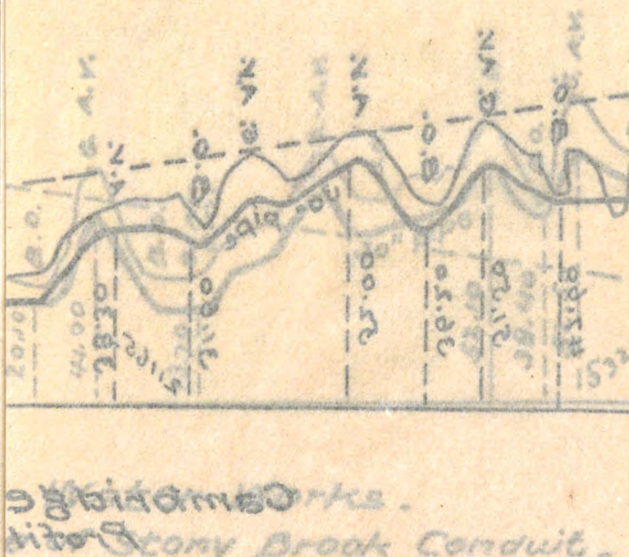
## New Stony Brook Conduit

The design of this conduit was to replace the old cast-iron conduit line of 30-inch cast-iron pipe, laid on bad grades, with an enlarged concrete structure from which the objectionable elevations should be eliminated. The conduit is entirely of concrete, 63 inches in diameter, 27,335.35 feet long, extending from Fresh Pond nearly to the center of Waltham. The greater portion of the conduit acts as an open canal or watercourse, but at two places, where the ground was low, it acts under a low head. At these points the concrete is reinforced with half-inch steel rods. The entire work was built by the city, almost entirely by Cambridge men, no contracts being made except for materials and supplies.

The cost of the conduit, including land damages, has been $575,000. After the conduit was put in service, a curious fact developed. One object of the new conduit was the elimination of the high grades at the lower end of the line. This was accomplished, but it was found that by the construction of this conduit the hydraulic grade line had been so lowered that there was a section just west of the terminus of the new conduit in Waltham which now was above the new grade line, and the same difficulties were repeated as were experienced at the lower end, viz., collection of air in the pipe at the summit and greatly reduced flow. This was remedied by relaying part of the 30-inch pipe on a new and lower grade in 1908.

The engineers of this work evidently overlooked the fact of the *altered position* of the hydraulic grade line! This is referred to here simply to illustrate the fact, so well known and ap-

preciated by all engineers of experience, of the ease with which an error of judgment may be made, even when great care is



## TAPERED CONNECTING RODS FOR HIGH SPEEDS

**[The Journal is in receipt of the following inquiry in regard to a suitable formula for the design of tapered connecting rods for high speeds, from Mr. Winslow H. Herschel, '96. Formulæ as given by Merriman and Unwin, Mr. Herschel finds unsuitable for his purpose, since they assume a rod of uniform section. Furthermore, Mr. Herschel questions Unwin's statement. "It is accurate enough to estimate the bending forces due to the oscillation of the rod as if it were a uniform rod of the diameter *d* at its greatest section" ("Machine Design," Part II, p. 105), for very high speeds. Communications may be addressed to Mr. Herschel, at 110 Governor Street, Providence, R.I.—Ed.]**

With the gradual increase in the speed of reciprocating engines, the question as to the stresses produced by the inertia forces becomes one of great importance. While there are a number of rules and formulæ for proportioning connecting rods, few, if any, of them contain the speed or any factor dependent upon it. It is evident that these rules have been derived from experience with low speeds, and that they do not apply to cases where the effect of the inertia forces cannot be neglectd.

A search through the literature on the subject shows that most formulæ for connecting rods are derived from Gordon's formula for columns, the load being perhaps expressed as the area of the piston multiplied by the pressure upon it, and the radius of gyration being expressed in terms of the maximum diameter of the rod. We may further find an equation for the maximum bending moment due to the inertia forces, it being assumed that the rod is in such a position as to make a right angle with the crank, and that the rod is of uniform section. Under these conditions the maximum bending moment will be at a point distant 0.4 of the length of the rod from the crank pin. Then there are purely empirical rules for determining the largest diameter of the rod, for locating the position of the section of largest diameter, and for finding the diameters of the necks, these latter diameters being derived either from the size of the piston rod or from the maximum diameter of the connecting rod.

Now the total stress in any section of a connecting rod is due to three causes, as follows:

$P$ = axial thrust in rod, due to the pressure on piston, and to the inertia force of piston, piston rod, and crosshead. The axial component of the inertia force of the connecting rod, which is comparatively small, may also be included in $P$.

$Mi$ = bending moment due to the normal components of the inertia forces of the connecting rod.

$Mf$ = bending moment due to $P$, being equal to $P \times f$, where $f$ is the deflection of the rod.

The stress due to $P$ is equal to $P/A$ where $A$ is the section of the rod, and if $S$ = section modulus, that is the moment of inertia divided by the distance to the extreme fibre, then the stress due to $Mi$ is equal to $Mi/S$ and that due $Mf$ is equal to $Mf/S$. Consequently, if we knew the values of $Mi$ and $Mf$ for various sections of the rod, it would be a very simple matter to find the maximum stress at those points.

When, however, we attempt to find numerical values for $Mi$ and $Mf$ for a given case we find considerable difficulty. If we assume that Gordon's formula (or some formula derived from it) gives correctly the combined stress due to the load $P$ and the bending moment $Mf$ (and there seems to be some doubt on this point), we still have the problem of finding out how much the stress will be increased by the bending moment $Mi$. Even if we had formulæ for $Mi$ and $Mf$ separately we could not assume the total stress due to these two bending moments to be equal to the sum of $Mi$ and $Mf$ divided by $S$, because the deflection $f$, upon which the value of $Mf$ depends, is determined in part by the bending moment $Mi$.

We have in reality not even a formula for $Mi$ or $Mf$ taken separately. The formula for $Mi$, already referred to, does not apply to our case because we have assumed a tapered rod, and if we should calculate the normal components of the inertia forces for each material point of which the rod may be assumed to be composed, we are met by the difficulty that the load is neither a concentrated nor a uniformly distributed one, and consequently neither the deflection nor the bending moment may

be determined by any simple formula. In the second place, there is an error in assuming that the maximum bending moment due to the inertia forces, that is, the maximum value of $Mi$, is at a section distant 0.4 of the length of the rod from the crank pin. For since the normal component of the inertia force, for a given speed, for a unit weight placed at one point in a rod, attains a maximum value for one crank angle, and for a weight placed at another point in a rod it attains its maximum value at another crank angle, it follows that the crank angle for which the sum of all the inertia forces perpendicular to the rod, or the resulting bending moment $Mi$, will be a maximum, will depend upon the distribution of weight in the rod, or, in other words, upon its taper. If, then, the maximum value of $Mi$ is not attained with a crank at right angles to the rod, we cannot assume that the section of maximum bending moment is located 0.4 the length of the rod from the end, because this location depends, in all probability, upon the position of the rod.

According to the various empirical rules, the largest section of a rod should be anywhere from the center to the crank end. It will be seen that if the speed is so low that $Mi$ may be neglected, the largest section should be at the center where $Mf$ has its maximum value. On the other hand, if the speed is high, and $P$ comparatively small, so that $Mf$ may be ignored, the maximum section should be at the point where $Mi$ has its maximum value. For intermediate cases the maximum section might lie between these two positions, or there might be more than one point of maximum section. There appears to be no case which would theoretically require a straight taper from one end to the other, and rods are made of this form mainly on account of ease of manufacture.

It will be seen that all the rules leave much to be desired, and that unless one is content to accept an empirical formula without knowing for what speeds it will be safe, the method of procedure must be about as follows:

Calculate the bending moments and deflections resulting from the normal components of the inertia forces, assuming that the rod is a beam under a uniformly distributed load.

Ignoring the increase in deflection due to the bending moment $Mf$, calculate the bending moments $Mf$ as equal to the load $P$, multiplied by the deflections obtained above.

The total bending moment for any section then equals $Mi + Mf$, and this sum, divided by the section modulus, and added to the direct stress $P/A$, will give the total maximum stress per unit area of section.

While the above method is not entirely satisfactory, it is given with the hope that some other reader of the HARVARD ENGINEERING JOURNAL will be able to present something better. What is wanted is a formula to give the maximum stress in a section of diameter $d$, distant $x$ from one end, in a rod with total length $l$, subjected to a load $P$, with $n$ revolutions per minute, when the crank angle is $a$, the diameter $d$ being a function of $l$ and $x$.

WINSLOW H. HERSCHEL, M. V. d. I., 1896

# HARVARD ENGINEERING JOURNAL

A QUARTERLY

DEVOTED TO THE INTERESTS OF ENGINEERING AND ARCHITECTURE AT HARVARD UNIVERSITY

Published four times during the college year by the Board of Editors of the Harvard Engineering Journal.



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| Single copies | .35 |

Address all communications:—

HARVARD ENGINEERING JOURNAL,
Room 218. Pierce Hall.
Cambridge, Mass.

Entered at the Post Office, Boston, Mass., as second-class mail matter June 5, 1902.

## ASSOCIATION OF HARVARD ENGINEERS

The second annual meeting of the Association of Harvard Engineers was held at the Harvard Union on March 20, at 6 o'clock. About fifty members were present. The secretary reported that, organized a year ago with sixty-three charter members, the Association now has a membership list of nearly three hundred, and this number is rapidly increasing. Over twenty-five per cent have become life members. The meeting discussed the question of adopting a program of action for the coming year. Several suggestions were offered, among others that of

inaugurating a Registration Bureau, by means of which recent graduates seeking positions might be put in communication with opportunities for employment. This matter, together with the question of making arrangements with the HARVARD ENGINEERING JOURNAL to serve as the official organ of the Association, were referred to the Council for investigation and action. The following list of officers was then elected for the ensuing year:

*President,* George S. Rice, S.B., '70.

*Vice-Presidents,* Bernard R. Green, S.B., '74; Hennen Jennings, C.E., '77; E. A. S. Clarke, A.B., '84.

*Secretary-Treasurer,* F. Lowell Kennedy, A.B., '92, S.B., '98.

*Members of Council for Three Years,* Philip W. Davis, A.B., '93, S.B., '95, James F. Sanborn, S.B., '99.

The complete list of officers includes the following additional members of the Council elected last year:

*For Two Years,* E. C. Felton, A.B., '79, Franklin Remington, A.B., '87.

*For One Year,* B. B. Thayer, C.E., '85, F. L. Gilman, A.B., '95.

After the meeting, the members joined with the undergraduate Harvard Engineering Society in the eleventh annual dinner of the latter organization. A notice of this dinner is given in another place in this copy of the JOURNAL.

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## ENGINEERING SOCIETY

January 22, 1909. — Mr. Paul Windsor, electrical engineer of the Boston Elevated R.R., spoke on "Improving the Efficiency of Existing Plants by a Careful Study of the Conditions."

In an established business such as that of the Boston Elevated R.R., any improvement in the efficiency can be accomplished only by a systematic investigation of the condition of the large number of cars now run by the company. An office list of all the cars is kept, which gives full information about

each car, its description, the type, size, and number of motors, and the repairs which have been made, as well as those which are necessary. The method of repairing motors from beneath rather than by lifting the car from the trucks, although more inconvenient from the standpoint of the mechanic, yet this method gives better access to certain parts of the mechanism, and has proved most satisfactory.

The workmen, also, have helped the efficiency of the plant, perhaps unknowingly, by endeavoring to have their tools and materials near the place of work. The managers have taken advantage of this, and have used labor-saving devices, and placed materials in suitable places for their use.

February 26, 1909. — Mr. J. P. H. Perry, '03, of the Turner Construction Company, New York, gave a very interesting lecture on "Reënforced Concrete Construction." The fine collection of lantern slides showed clearly the methods used in this type of construction for placing the forms, the steel reenforcement, and the concrete. Some of the beams shown have a span of twenty-two feet, with a depth of seven feet, supporting the front wall of a building over a large center doorway. Another set of girders of fifty feet span affords a large floor space. A reënforced concrete truss, having an arched top chord and a steel tie-rod as lower chord, was an unusual type.

The ability of concrete to resist fire was well shown by views of a concrete building in which a fire occurred in one floor and was confined to that part of the building, and another building of brick, where the attention of the firemen was chiefly directed.

One of the best examples of concrete construction was shown in a building where the grouping of the windows was carefully studied and the corners of the building were made especially massive, and the whole ornamented with a Greek cornice projecting six feet beyond the wall.

Types of modern mill building construction were also shown wherein expansion joints for long buildings were made necessary on account of the expansion of concrete, which is practically the same as that of steel. Various types of exterior finishing were illustrated, and also the adaptability of concrete for residences.

March 19, 1909. — Mr. A. S. Cushman, Assistant Director in the Office of Public Roads, Washington, D. C., gave an illustrated lecture on the "Work of the U. S. Office of Public Roads."

This government office offers employment to students in engineering and road-building. Civil service examinations, under the title of engineer student, are required. Under the direction of this office, is given to these students a thorough training in the science of road-building and a complete study of suitable road materials, including chemical analyses of tar and asphalt binders. The states and counties all over the country send to this office for capable men to take charge of road-building, and the demand is greater than the supply.

The remarkable collection of lantern slides showed the wonderful improvements that have been made in roads in various sections of the country, especially in the South and West, where little money and thought had been expended for good roads, simply because the people did not know what materials were suitable or how to use those which were at hand. Frequently the investigation of a region by an expert will reveal suitable materials for roads. A sandy section is often found near a clayey section, and it has been shown by experience that a mixing of sand and clay in certain proportions makes a very good road. In one instance, a very sticky clay road was made over by burning the clay, crumbling and rolling the product, and thus making the road far superior to its former condition.

The most important consideration in road-building is that of drainage, for without suitable channels for carrying off surplus water, no road can be well built. In some cases the roads seem to have become the drainage channels for the adjoining land rather than highways. In flat country this question is more difficult than in hilly country. In reference to the effect of deforestation, on this question the speaker protested strongly, not only against the terrible destruction and waste of the forests for purposes of making pulp, but also the evil effects on the rainfall and drainage of the whole region where this has taken place.

After the building of a road, its maintenance is of primary importance. This is accomplished by two methods. The system of intermittent repairs, as is used largely in this country, is being superseded by the system of continuous maintenance, as carried on in France, where great satisfaction is secured. Not only should a road which gets hard usage be repaired, but, also, a road should be used a certain minimum amount to prevent its destruction by weeds and the effects of rain.

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## CIVIL ENGINEERING CLUB

February 23, 1909. — Mr. Stephen De M. Gage, of the Lawrence Experiment Station of the Massachusetts State Board of Health, gave an illustrated lecture on "The Lawrence City Filters."

The source of water supply of the city of Lawrence was for several years a long filter gallery dug beside the Merrimac River, and built of open masonry, 300 feet long by 8 feet square. It became quite evident that the high death rate in the city, due to typhoid fever, was directly traceable to the water supply — the Merrimac River — which receives the sewage of large cities above Lawrence. So, in the 80's, the city authorized the building of a large sand filter with the object of reducing this death rate. The filter, after construction, was divided into two parts by a concrete division wall in order to facilitate the operation and cleaning of the filter. Until 1904 the cleaning and removal of the sand from the filter was done by manual labor. After that date a hydraulic lift and hoppers were used for removing, cleaning, and replacing the sand, and a great economy resulted in using this process. In this sort of an open filter the operation of cleaning was especially difficult in winter, since it was often found necessary to remove ten or more inches of ice before the sand could be reached. Also, the rate of filtration in winter was very much slower and the supply became dangerously low.

Consequently in 1906 a new filter was authorized and construction was commenced. The old filter of about two and one-half acres was merely a hole in the ground. The new filter of

three-quarters of an acre is built entirely of concrete masonry of the usual type of covered filter. It is 27 bays long and 7 bays wide, each being 15 ft. 4 in. center to center of the columns. The central portion of the roof is reënforced with steel rods, since it is there that the apparatus for washing the sand is placed.

The objects in filtering the water are: first, to strain out the suspended matter, and second, to remove the bacteria. A newly constructed filter must first be matured, a process lasting from two to three months, after which the water from it can be used. The bacterial efficiency of this new filter is about 99%, and the wonderful effect is shown in the decrease in typhoid fever cases in the city, where the the death rate from that cause has been, at times, since the building of the new filter, below the average for the state.

March 12, 1909. — Mr. J. A. Holmes, Assistant Engineer on the Charles River Basin Commission, spoke on "The Charles River Dam."

By aid of numerous lantern slides, the speaker showed the improvements already made and contemplated in the Charles River Basin. These will be accomplished by keeping the water level at a fixed elevation and by the construction of parkways along the river banks. Views of foreign river parks show them to be small in comparison with this undertaking.

The basin is maintained by an earthen dam with concrete retaining walls faced with granite. Many wooden piles have been driven under the retaining walls to give them stability. The dam is provided with a lock 400 feet long, 40 feet wide, and 30 feet deep, with 18 inches of water over the sill at low tide. It is reënforced with steel rods, and contains pipe conduits for underground electric wires.

When this dam and basin are completed, they will form one of the largest and most beautiful of river parks in the world.

March 24, 1909. — This meeting of the Civil Engineering Club was held in F. A. Armstrong's room, Stoughton 32, and was a success socially as well as being instructive. Mr. William McK. Griffin, '06, was the speaker, and he told of the pleasure which

he derives from the Civil Engineering Club of New York, and also of the enjoyment which meetings of the undergraduates here ought to afford us.

The subject of Mr. Griffin's talk was the "Pennsylvania R.R. Tunnels Under the East River." These tunnels, 23 feet in diameter, are dug through both rock and soft earth. Under the river, compressed air, ranging in pressure from 20 to 35 lbs. per square inch, was used during construction. The progress through some of the softer materials was from 18 to 20 feet per day. The interesting part of the result is the accuracy with which the tunnels were completed, both in alignment and elevation, no greater error in line than one quarter of an inch, and three-eighths of an inch in levels. This was accomplished by continually making checks on the work as it progressed. Other features of interest are the safety devices, called screens, placed at intervals through the tunnel during construction. These are semi-circular diaphragms placed in the upper half in order to prevent completely flooding the tunnel in case a blow out should occur, and afford means of escape for workmen. Besides this safeguard, there is a hospital lock, provided with a couch and telephone for summoning assistance.

In this work, as well as on all engineering construction, many ingenious methods of doing the instrument work were resorted to; in fact, they were applications of simple principles which proved successful.

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## ELECTRICAL CLUB

On February 16, the members of the club were entertained by Mr. Hammond V. Hays, until recently chief engineer of the Bell Telephone Company. Mr. Hays outlined the development of the telephone up to the present, and spoke of the possibility of future improvement, emphasizing the need in telephone engineering for men of technical education.

On March 22, at a joint meeting with the Mechanical Club, C. J. H. Woodbury, A.M., Sc.D., gave an illustrated lecture on "The Development of the Modern Mill." Mr. Woodbury did

not go into the details of mill operation, but showed with the aid of lantern slides the advancement of mill architecture, the improved lighting and ventilation, and the fireproof construction.

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## HARVARD ENGINEERING DINNER

The annual dinner of the Association of Harvard Engineers and the Engineering Society was held in the Harvard Union on Saturday evening, March 20. The 140 men present were very enthusiastic, and so made this one of the best engineering gatherings held in Cambridge.

The Association of Harvard Engineers held a reunion and business meeting in the trophy room before the dinner. About 70 graduates were present.

At the dinner, Mr. Joseph R. Worcester, '82, president of the Association of Harvard Engineers for the past year, was presiding officer. He introduced as the first speaker Professor Kennedy, secretary-treasurer of the Association, and chairman of the Division of Engineering. Professor Kennedy spoke of the interest which the graduates are showing in the new Association which was organized last year with a membership of 63, and which now has 300 members. This uniting of Harvard engineers is not only invaluable to the graduates themselves, but will also have a large influence in engineering education at Harvard.

Mr. M. T. Rogers, '08, President of the Engineering Society, told of the growth of the undergraduate organization during the past eleven years and of the important place that this has in the University. It is at this dinner that the students of the University have the opportunity of extending their welcome to the recently appointed professors — Professor Swain and Professor Clifford.

Hon. J. J. Myers, '69, trustee of the McKay Fund, had the opportunity of telling us how Gordon McKay became interested in Harvard. The speaker eulogized Gordon McKay for his breadth of character and scientific knowledge, and told of the remarkable friendship which grew between the late Dean

Shaler and the Harvard benefactor, who were neighbors here in Cambridge. It was largely through their friendship that this great bequest was made to the University.

Mr. Hennen Jennings, '77, a mining engineer, traced the development of mining engineering, and more especially that of the Conery Company of Ruby, Montana. This company was the pioneer in the use of the gold mining dredge, and was the concern in which Gordon McKay was especially interested. The success of this company is partly due also to the valuable advice and the scientific knowledge of mining which Dean Shaler gave to Mr. McKay.

Dean Wallace C. Sabine, '88, spoke briefly, welcoming the new professors, and emphasizing the debt which we owe to the present and past members of the teaching staff.

Professor Harry E. Clifford expressed the belief that, in teaching, congenial co-workers are invaluable, and he felt that the reception which had been given to Professor Swain and himself here assured them of this personal association, which will bring about ultimate success to this new Graduate School of Applied Science.

Professor George F. Swain spoke of his great interest in Harvard, and of the extraordinary opportunities offered through connection with this University. He is entirely in sympathy with the step which Harvard is taking toward placing the profession of engineering on a higher plane.

Mr. E. L. Lincoln, '08, editor of the ENGINEERING JOURNAL, pointed out the benefits which the JOURNAL affords its subscribers, and humorously showed how the graduates can all help by sending in articles for publication and inducing friends to subscribe for it.

The dinner closed with the singing of " Fair Harvard."

## CLIPPINGS

Typhoid fever deaths in Chicago for 1908 totaled 338, or at the rate of 15.6 per 100,000. This was 12% below the rate for 1907, about 33% lower than the average for the last ten years, and 91% below the record-breaking figure of 1891, when the appalling rate of 173.8 per 100,000 was recorded. For the nine years since the opening of the drainage canal, the average rate per 100,000 was 21.1, as against 57.7 for the nine years before the canal was opened. According to the bulletin of the Chicago Department of Health for February 20, 1909, "if the pre-channel typhoid rate had prevailed during the last nine years there would have been 10,035 deaths from typhoid fever in that period, or 6,014 more than actually occurred. Figuring on the basis of the legislative value of a human life, this saving represents the sum of $64,140,000, or more than the entire cost of the drainage canal to date."

—*Engineering News.*

According to *Engineering,* the so-called Daylight-Saving Bill has been read for the second time in the House of Commons. "Put briefly, the change proposed by the Bill is that on the third Sunday in April in each year all clocks shall be put forward one hour, so that noon may fall at what would, under present conditions, be 11 A.M. On the third Sunday in September this process is to be reversed, the present normal noon being restored. The two changes would take place on dates which would not be earlier than the 15th nor later than the 21st of the months named; for the present year they would occur on April 18 and September 19, and as these days are respectively the 108th and 262d days of the year, the change of noon would be in force for 154 days. The advocates of the Bill claim that everybody would thus have 154 hours more daylight placed at his disposal for recreation or other purposes."

The wireless telegraph operators at Mount Wilson, Cal., state that they have recently been receiving signals in some

curious code that is neither Morse nor Continental nor anything else legible. These signals are quite strong, and the operators have been conjecturing that they may come from Mars. Mr. Nikola Tesla writes us on this surmise: "I do not believe that the operators are observing the same disturbances which I have already noted in Colorado, because I had to use a device of wonderful sensitiveness, which I have reason to believe is not yet known to the wireless people. I rather think it is likely that a plant somewhere is producing stationary waves, and I have an idea that it must be located in Japan, as the Japanese saw me during 1900 and adopted my system at that time. Should the reports continue I shall make an investigation. It will not be difficult, if such is the case, to locate the transmitting plant very closely."

— *Electrical World.*

A bore hole 7,370 feet deep is being drilled near Rybnils, in southwestern Germany, says the *Zeitschrift des Vereines Deutscher Ingenieure.* By December, 1908, it had reached a depth of 7,070 feet, with a diameter of two inches.

— *Engineering News.*

Six Curtis 1500-k.w. turbo-generators have arrived at the Isthmus of Panama for installation at Gatun and Miraflores, where power-houses are now under construction for the permanent electric power generating plants, which will supply electrical energy for the work of construction of the locks at Gatun, Pedro Miguel, and Miraflores. . . . All operations in building the locks will be conducted by electric power from the time the raw material is received in scows coming up the old French canal until the concrete is in the forms at the locks.

— *Electrical World.*

## BOOK REVIEW

THE STEAM TURBINE. By James A. Moyer.

This volume is the result of much painstaking work on the part of its author to place before students and practical men the principles and details of the steam turbine. Without going very deeply into the mathematics of the subject, it is, nevertheless, one of the most useful of the recent treatises, and a practical engineer can read it without fear of being swamped by formula.

The first chapter, covering the history of the steam turbine, is made brief. The author gives only enough of this side of the subject to bring out clearly the two distinct types, reaction and impulse wheels, as they were invented centuries ago.

The short chapter on the elementary theory of heat is well written, and so clear that it will enable any student to understand most of what follows without aid from books on thermodynamics. The entropy diagram presents the only difficulty, but it must be remembered that this method of exhibiting the work done by heat is much more recent than the ordinary indicator diagram. Furthermore, the latter can be taken by any operating engineer, and understood almost at a glance.

The chapters which follow, on nozzle and blade design, are the most important in the book. They are well written, notwithstanding the fact that in spots they might have been made clearer.

It is not the intention here to go into an analysis of the succeeding chapters, but merely to call attention to the fact that every chapter in the book is selected with judgment, so as to complete in a practical way all aspects of the machine, even going into the tests and economics of machines now in operation.

That the writer is up-to-date is well shown by the chapter on the low-pressure turbine for operation in connection with the reciprocating engine.

The book has been used at Harvard for a senior class in mechanical engineering, and has been subjected to a very searching examination for mistakes and lack of clearness, but it has

stood the test well, and has been found to answer admirably as a college text-book. One of the pleasing features of the printing is the method of calling attention to important principles and facts. These are printed in bold-faced type. Thus, a reader can catch at a glance a general idea of the contents of a paragraph, and can refer readily to any part. As a good elementary treatise, the book can be safely recommended.

---

## TRADE NOTE

### The Ventilation of Gymnasium Lockers

In equipping the gymnasium locker room the ventilation is a matter which should receive most careful attention. Ventilation pays here as well as in any other part of the gymnasium; in fact, it is of greater importance than in most portions of the building. A locker room containing a large number of lockers is liable to become decidedly disagreeable and unhealthy because of the foul odors from the sweaty clothes hung for hours in the lockers. This is especially true in the football season. If natural ventilation is depended upon, the odors escape very slowly, and the drying of the garments is so retarded that they become mildewed, especially those of students not on teams, for such students usually frequent the gymnasium only at intervals.

In the method often used the air is drawn out of the locker room by means of a fan blower (exhauster), but this is usually unsatisfactory, for the odors are drawn from the lockers into the locker room, which becomes more unhealthy than ever. Steam pipes have been placed beneath the lockers so that the warm air rising in the lockers will dry out the garments. While this is a decided improvement, it is but partially satisfactory.

A system which meets all requirements is as follows: Steam pipes to warm the air are placed beneath the lockers, and each locker is connected at the top to a main exhaust duct of galvanized iron. This duct leads to the fan, which is driven by a motor, direct-connected if conditions of speed and volume permit, if not, by means of a belt. The air is drawn from the floor by the fan into the space in which are the steam pipes and

then up through the lockers. While passing through the lockers the warm air takes the moisture and odors from the garments into the main duct; the fan maintaining a continuous flow and discharging the air out of doors. For this work the small steel-plate fan should be selected, for it gives the necessary volume at low pressure.

For a locker room having 150 lockers, the cost of installation, including the galvanized-iron work, fan, and motor, is, approximately, $350; thus it is seen that the expense of this installation is exceedingly small compared with the great benefits derived by a large number of students. The B. F. Sturtevant Company of Hyde Park, Mass., has made investigations of locker room conditions, and manufacture and install this system.

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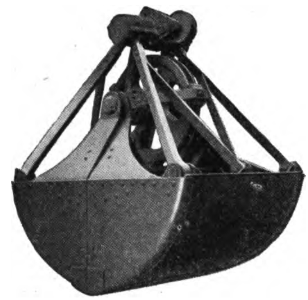

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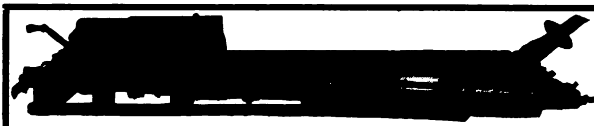



JUNE, 1909

# HARVARD ENGINEERING JOURNAL

A QUARTERLY
DEVOTED TO THE INTERESTS OF
ENGINEERING AND ARCHITECTURE
AT HARVARD UNIVERSITY

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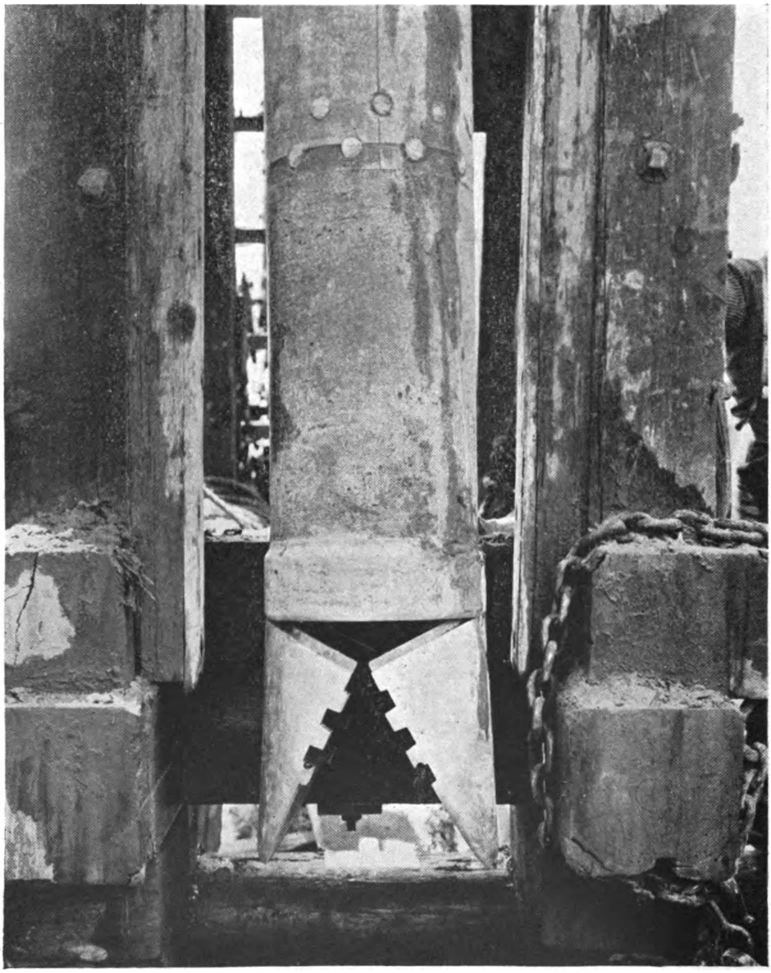


*Frontispiece* "ALLIGATOR" POINT—OPEN *See page 292*

# HARVARD ENGINEERING JOURNAL

A QUARTERLY

Devoted to the interests of Engineering and Architecture of Harvard University

VOL. VIII JUNE, 1909 NO. 2


## RUN-OFF OF SOME REPRESENTATIVE STREAMS OF THE UNITED STATES

BY M. T. ROGERS AND H. U. RANSOM

The object of this article is to present to those who may be interested in such subjects, the results of a study of stream-flow and run-off in different parts of the United States. The data have, for the most part, been taken from the records of the United States Geological Survey, as published in the Water Supply and Irrigation Papers. It is not the intention to go into the details of the methods of making the measurement of rainfall and run-off, which may be found in treatises on water-power and hydrography, nor to make an exhaustive study of the evaporation, temperature, geology, topography, and vegetation, conditions which largely affect stream-flow. These will be touched upon in a general way, where any one or several, may be important with any certain river, but more especial attention will be given to the effect of storage conditions. The hydrographs of the rivers considered are shown in the diagrams. The average monthly flows in second feet per square mile of drainage area are plotted in order of dryness: one curve showing the average values for a term of years, and the other the flow of the driest year in that term. By second foot per square mile is meant the number of cubic feet per second passing a certain station divided by the number of square miles of drainage area above that point. The monthly average is obtained by averaging the flow in second feet per square mile for each day.

In 1888, the United States Geological Survey began to collect data in regard to the water-power of the country at large. The object of this work was set forth by Major J. W. Powell,

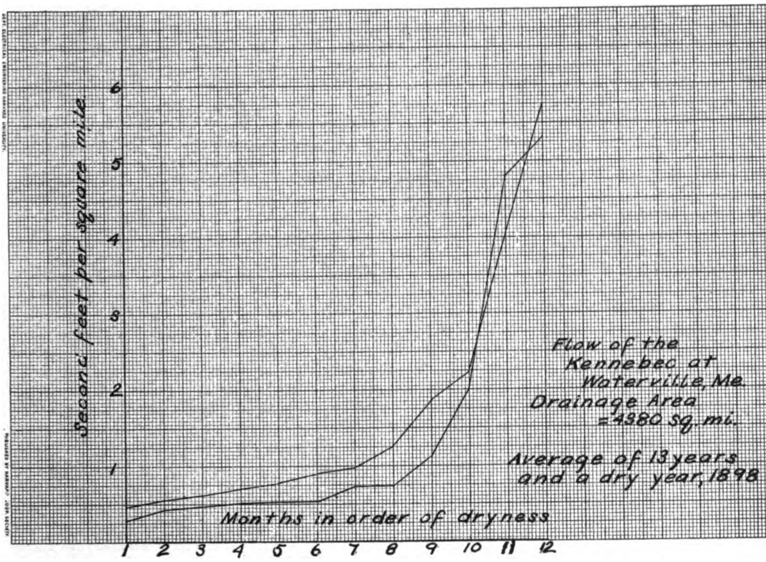
Director of the Survey, in the Tenth Annual Report, 1890: "It will be necessary to gage a certain number of representative streams at all seasons of the year, so as to ascertain their total discharge and its seasonal distribution, and also to gage a greater number of streams at certain seasons determined to be critical."

The Survey has developed methods for general stream gaging and has collected data in regard to the flow of streams in all parts of the United States. These data are published by the Department of Agriculture, in the Water Supply and Irrigation Papers, and in the Annual Reports of the Geological Survey. The records show, wherever possible, the distribution of flow over several consecutive years; for some of the smaller streams, where stations have recently been installed, the measurements cover shorter periods of time, but it is reasonable to suppose that such records are more accurate, as instruments and methods of measurement have improved. At present, there are very few sections of the country which have not been worked over to a greater or less degree, so that engineers interested in enterprises involving the use of water find it to their advantage to be acquainted with the Geological Survey records. It may be said, in passing, that Water Supply and Irrigation Paper No. 119 is an index of the publications relating to the flow of rivers, and gives references to all records kept by the Survey up to the end of the year 1903.

### THE KENNEBEC

The Kennebec River basin has a total area of 5,970 square miles; about one-fifth the area of the state of Maine. The river and its tributaries furnish some of the best water power in the country, and the large proportion of timbered land has made it famous as a log-driving and lumbering stream. The power is used largely in the manufacture of pulp, paper, cotton, and woolen goods.

The conditions in the Kennebec basin are unusually good for a water-power stream, because of the large storage at the headwaters. Moosehead Lake is the source of the main river. This lake, with all its tributaries, has a total drainage area of 1,240 square miles, and acts as a great collecting basin, by which the flow of the river may be controlled. In addition, there are many other lakes and ponds in the basin further south,


Second feet per square mile
1
2
3
4
5
6
Flow of the
Kennebec at
Waterville, Me.
Drainage Area
=4380 sq. mi.
Average of 13 years
and a dry year, 1898
Months in order of dryness
1
2
3
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5
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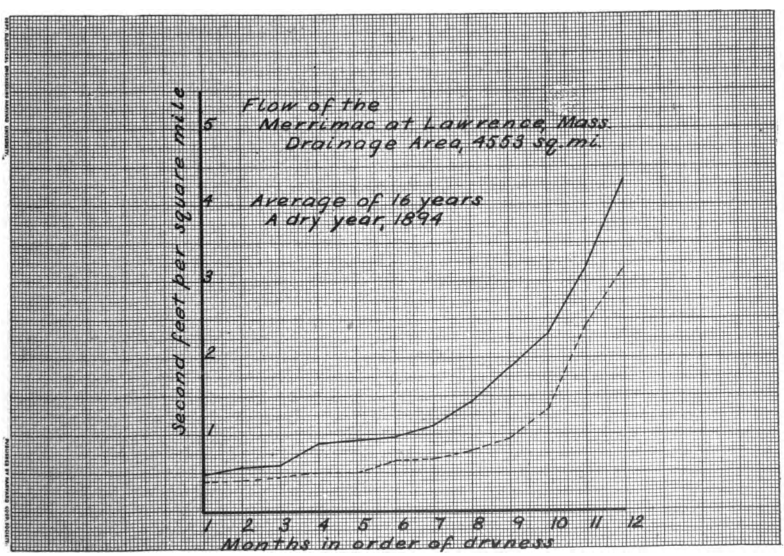
10
11
12


Flow of the
Merrimac at Lawrence, Mass.
Drainage Area, 4553 sq. mi.
Average of 16 years
A dry year, 1894
Second feet per square mile
1
2
3
4
5
1
2
3
4
5
6
7
8
9
10
11
12
Months in order of dryness

which afford a large additional storage. According to figures in the "Water Power of Maine," by Walter Wells, 1869, there are 311 lakes and ponds and 1,084 streams tributary to the Kennebec. The mean precipitation over the whole basin is about 39 inches per annum, a considerable portion of which falls as snow and lasts well into the spring. Ice is usually in the river four months of the year.

The hydrographs shown are plotted from figures taken from Water Supply Paper No. 198. The records extend from 1893 through 1905. The flood months are April and May, and the lowest flows occur in the winter months, after the storage ponds have been drawn down through the period of low precipitation in the fall, and the winter supply is fixed and unavailable as snow.

## THE MERRIMAC

The Merrimac was one of the first streams in the country to be developed, and is famous for the industrial cities which have been built upon its banks because of the splendid water power available. Lawrence, Lowell, Nashua, and Manchester, to say nothing of the smaller towns along the river, owe their positions as leading manufacturing cities to the river upon which they are built. It is said that the Merrimac turns more spindles than any other river in the world.

Its drainage area is very similar, geologically, to that of the Kennebec. The upper branches rise in the White Mountain district, while at the foot of the mountains is Lake Winnepesaukee, a good storage and equalizing reservoir, with a surface of nearly 100 square miles. Of many other smaller lakes, Squam is the largest, with about 14 square miles of surface. There are very few streams of any size running into either Winnepesaukee or Squam. The rainfall, according to government records, is a trifle more than the average on the Kennebec basin.

In Fig. 2 are shown the hydrographs for the Merrimac, as plotted from data procured at Lawrence, Massachusetts. The drainage area above this point is 4,553 square miles, and the records are available from 1890 through 1905. Comparing the average values with those of the Kennebec, it will be seen that, with the exception of the third month, the flow in cubic feet per

second per square mile of the Merrimac exceeds that of the Kennebec through the tenth month. During the eleventh and twelfth months, the latter takes a considerable jump.

Considering the similarity of the two watersheds, the greater average flow of the Merrimac is probably due to the slightly larger precipitation during the first ten months. The greater flood flows of the Kennebec are due to the fact that there are greater amounts of snow about the headwaters of this stream, which, when melting first begins, considerably increase the volume of the run-off.

### THE HUDSON

The drainage area of the Hudson, compared with those of the New England rivers, is distinguished by the extent of its ground storage. The hydrographs are taken from the records of flow at Mechanicville, N. Y., given in the report of the State Engineer for 1905. The size of the tributary basin, 4,500 square miles, is almost exactly the same as that of the Merrimac above Lawrence, and comparison of the curves shows a very close similarity in the flow of the two rivers. The yield of the Hudson is consistently slightly larger than that of the Merrimac, although the yearly rainfall on its basin is a little less and the pondage comparatively small. We must seek the cause of this increase in changed evaporative conditions, and the equivalent of the Merrimac's pondage in the extensive alluvial deposits of the Hudson basin, particularly the Mohawk Valley. This characteristic of the Hudson, contrasted with the thinly covered slopes and large proportionate water surface of the New England river, accounts also for the larger proportion of run-off to rainfall.

The State of New York and the companies having developments on the river have joined in a scheme to create large storage reservoirs capable of adding 52 billion cubic feet to the flow of the low periods. Certain new plants on the river have provided for an additional capacity, after this project has been completed, equal to that at present installed. Thus this storage volume is expected to double the economic capacity of the river.

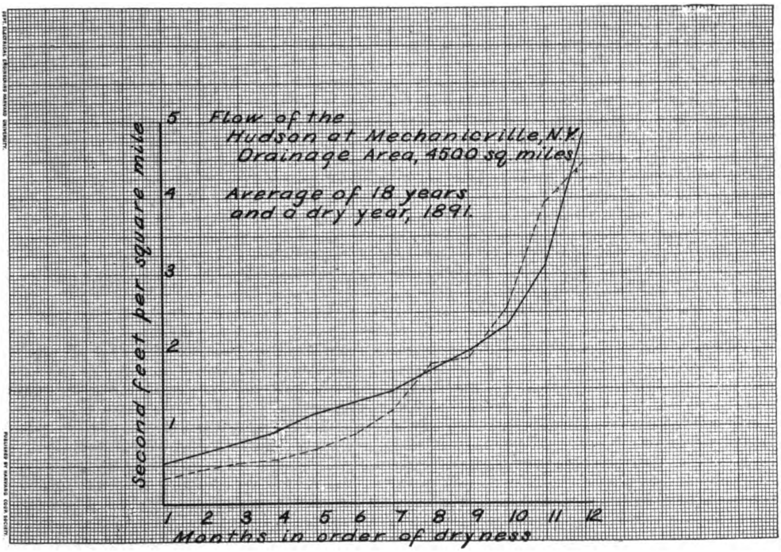
### THE SUSQUEHANNA

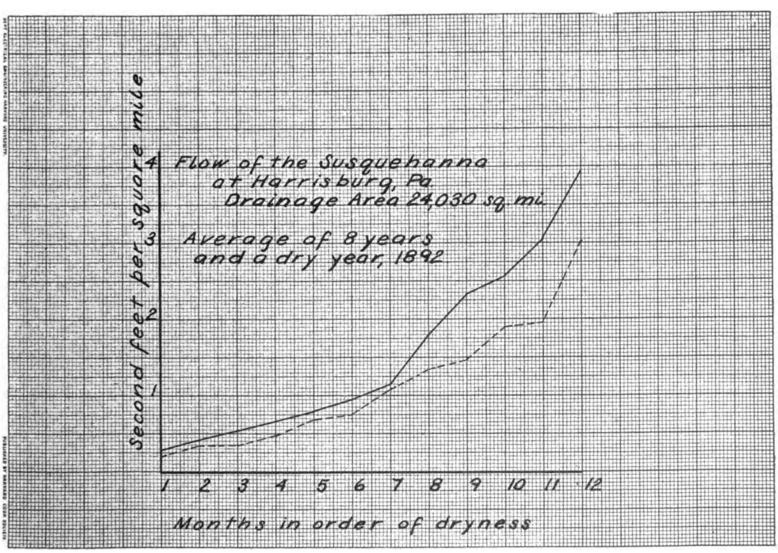
The Susquehanna is the stream of greatest volume on the Atlantic slope, having a total drainage area of approximately 27,400 square miles. It has its source in the State of New York, at an elevation of over 1,000 feet above sea level, and flows through central and eastern Pennsylvania, the great anthracite coal region of the United States. This proximity of fuel in large quantities for the generation of steam has been one of the reasons why water-power has not previously been developed to any large extent on this river.

The other great drawback to such development is the uncertain character of the stream. The slopes of its basin are steep and rocky, so that the rain which falls has little tendency to percolate. For this reason there is practically no ground storage to increase the dry weather flows; conversely, the spring rains run off so quickly as to cause great floods. Williamsport, on the west branch of the Susquehanna, was one of the leading lumber centers of the country. At present the city is in a state of decline, as the hills have been fully stripped, and it is believed by the inhabitants of the district that the floods have been greatly increased in severity during the last few years.

The amount of rainfall is about the same as that on the basins already considered: during 14 years the annual amount has varied from 31.4 to 44.3 inches, with a mean of 39.4 inches.

The Susquehanna is a very good example of a river which has splendid power possibilities, provided the rainfall can be satisfactorily stored. It has an unusual advantage in that a large part of the total fall of the river is in the last few miles of its flow, the region known geologically as the Piedmont plateau. From Highspire, near Harrisburg, to its mouth, the length of the river is 63 miles, and in that distance the drop is 286 feet, an average fall of 4.5 feet per mile. With good storage, which would guarantee a dependable flow throughout the year, water-power could be developed in this district and be easily transmitted in the form of electric energy to many large cities within a radius of 50 to 100 miles, where the demand for such power is surely great. The plant now under construction at McCall's Ferry aims to supply such electric power — its success would be much more certainly assured if the storage on the stream were greater.


Flow of the
Hudson at Mechanicville, N.Y.
Drainage Area, 4500 sq miles
Average of 18 years
and a dry year, 1891.
Second feet per square mile
Months in order of dryness
1 2 3 4 5 6 7 8 9 10 11 12
1 2 3 4 5


Flow of the Susquehanna
at Harrisburg, Pa.
Drainage Area 24,030 sq. mi.
Average of 8 years
and a dry year, 1892
Second feet per square mile
Months in order of dryness
1 2 3 4 5 6 7 8 9 10 11 12
1 2 3 4

### THE POTOMAC

The flow of the Potomac closely resembles that of the Susquehanna, although slightly smaller. The basin above Point of Rocks, at which place the records of run-off are taken, is hilly and steep, with but little storage. The hydrograph shown in Fig. 5 is an average of eight years.

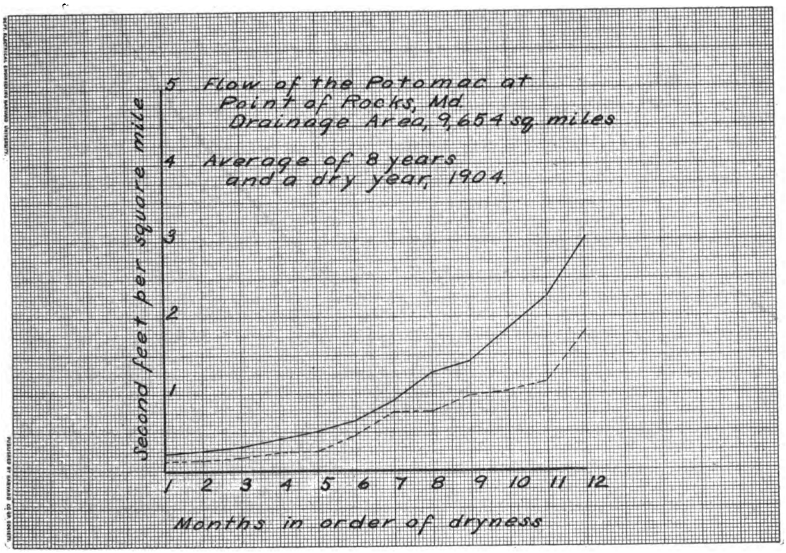
The rainfall averages about the same as that on the Susquehanna, 40 inches annually, and the percentage of run-off is high, about 42% for the year. The Potomac would be a good power stream if the run-off were more equable through the year. Good dam sites abound, the character of the banks is generally favorable for dams, and the fall per mile great in the lower portion of the stream. But while the total energy of the river is large, its economic capacity is low.

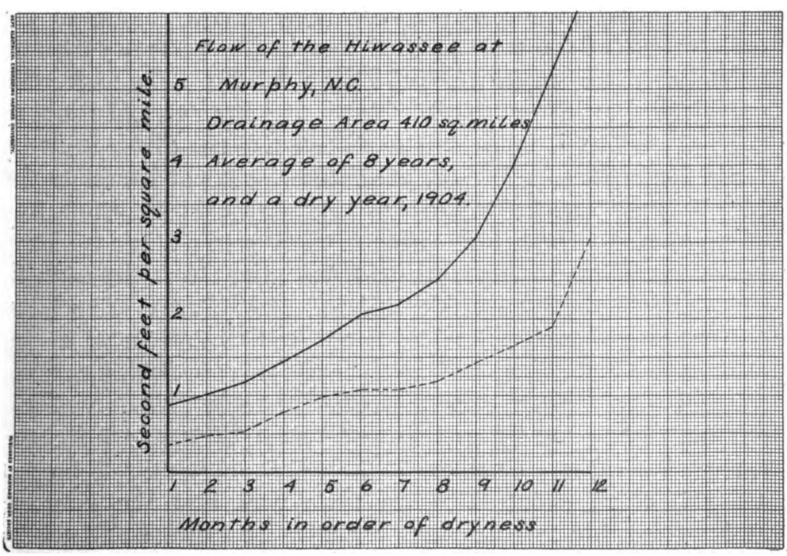
### THE HIWASSEE

The Hiwassee at Murphy, N. C., is typical of a large number of rivers which have their headwaters in the mountains where Virginia, the two Carolinas, Georgia, Alabama, and Tennessee nearly join boundaries. The watershed in this region possesses qualities which make the streams flowing from it among the best power propositions in the United States. The rainfall is higher here than in any other part of the country, except the slopes of Washington and Oregon, and it is very well distributed through the year.

No large percentage of the annual precipitation is stored through the winter as ice and snow, to be released all at once in the spring, causing the disastrous floods of our northern rivers. The slopes are fairly steep, a condition which produces a large percentage of run-off from the rainfall, and well covered with trees, which produce a layer of spongy humus on the top of the ground, retaining most of the water for a time, so that the daily flow is not so flashy as might be expected of rivers with comparatively so little pondage. The flow per square mile available economically is larger than that from any other watershed which has come within the knowledge of the writers.

Similar to the Hiwassee are the Tennessee, the upper Yadkin, the Chattahoochee, the upper Savanna, and the Alabama.


Flow of the Potomac at
Point of Rocks, Md.
Drainage Area, 9,654 sq. miles
Average of 8 years
and a dry year, 1904.
Second feet per square mile
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10 11 12
Months in order of dryness

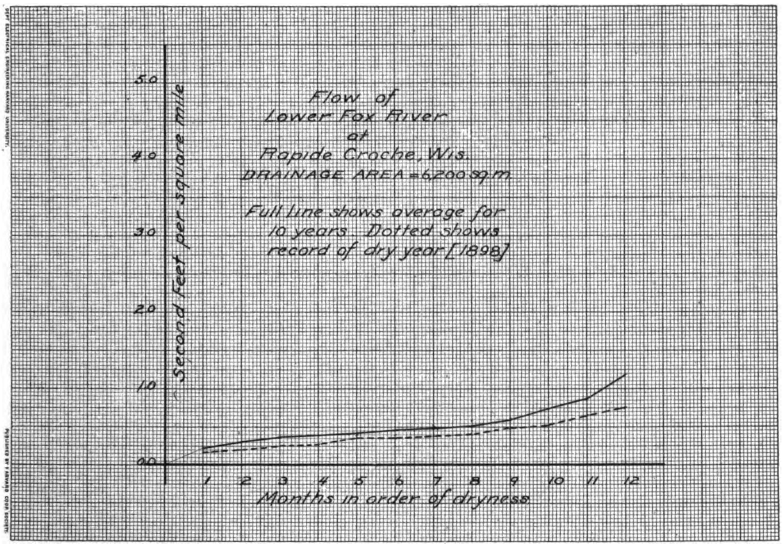

Flow of the Hiwassee at
Murphy, N.C.
Drainage Area 410 sq. miles
Average of 8 years,
and a dry year, 1904.
Second feet per square mile
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10 11 12
Months in order of dryness

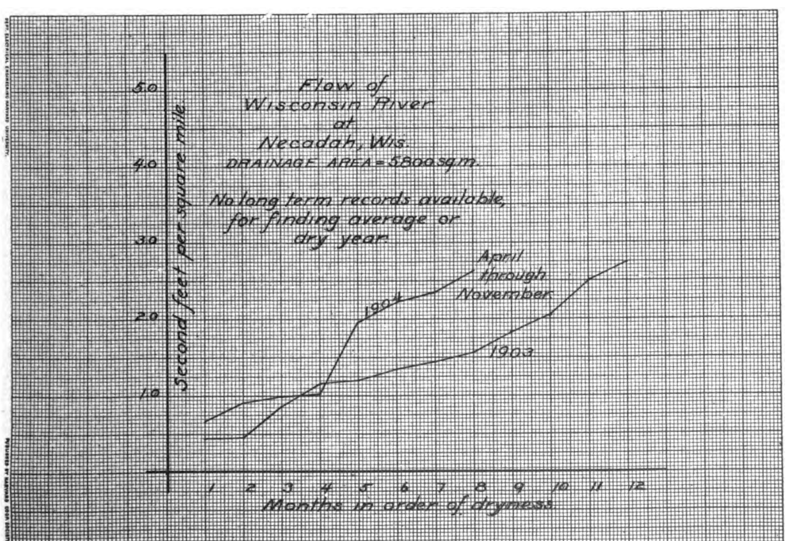
The rivers of West Virginia and Ohio, which rise in the mountains and flow down the western slopes, emptying, for the most part, into the Ohio, have much the same character as their eastern neighbors, the Potomac and the Susquehanna, while in the mountainous region. The rainfall averages annually about 40 inches, but there is no storage. The government has for some time been considering the advisability of constructing large storage basins near the headwaters of some of these streams, that the flow might be made more uniform. It is the general opinion that such a step would prove of great benefit to water power developments, but it is still an open question whether it would have the same effect on navigation. Many of these streams are navigable and largely used by traffic.

As these rivers leave the mountains they run into low flat plains, where the flow is very low during dry periods and where terrible damage is done by the floods during the spring freshets.

### RIVERS OF WISCONSIN

Wisconsin is a state rich in water power resources. A wide and comparatively flat highland crosses the northern part of the state, ranging in elevation from 1900 feet above sea level in the eastern part of the state to 1000 feet in the western part, and extending to within 30 miles of Lake Superior. The rivers rise on this plateau in a network of lakes and swamps which are so intermixed that it is difficult to distinguish the divide between those flowing east and those which flow south and west to the Mississippi. The fall to the north and east is very abrupt, and offers excellent opportunities for development. While the drop is not so sudden to the south and west, the rivers draining in these directions have considerable fall and volume. The lakes and swamps offer considerable storage, so that the run-off in dry periods is about 0.3 second feet per square mile. The average rainfall for 25 years over the entire state is 32.3 inches per annum, distributed by seasons as follows: Winter, 4.7 inches; spring, 7.6 inches; summer, 11.7 inches; autumn, 8.3 inches. Of this total, about 33% finds its way into the streams. It is interesting to note that over 60% of this rainfall comes in the summer and autumn months, thus compensating the great


Flow of
Lower Fox River
at
Rapide Croche, Wis.
DRAINAGE AREA = 6,200 sq.m.
Full line shows average for
10 years. Dotted shows
record of dry year [1898]
Second Feet per square mile
5.0
4.0
3.0
2.0
1.0
0.0
1
2
3
4
5
6
7
8
9
10
11
12
Months in order of dryness


Flow of
Wisconsin River
at
Necadah, Wis.
DRAINAGE AREA = 5800 sq.m.
No long term records available,
for finding average or
dry year.
April
through
November
1904
1903
Second feet per square mile
5.0
4.0
3.0
2.0
1.0
1
2
3
4
5
6
7
8
9
10
11
12
Months in order of dryness.

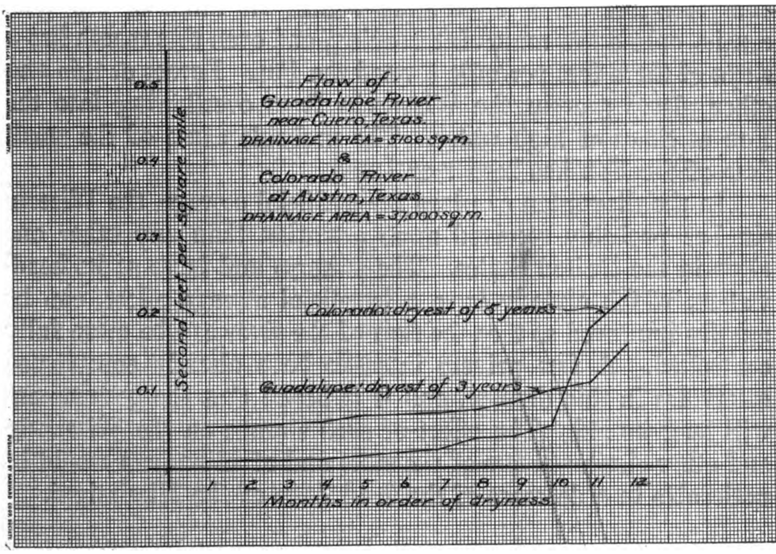
loss due to the growing vegetation, from which cause the flow of the rivers of this latitude is usually at its lowest during this period of the year. The winter months have a smaller precipitation and consequently a less flow. It is well that the evaporation is least during these months.

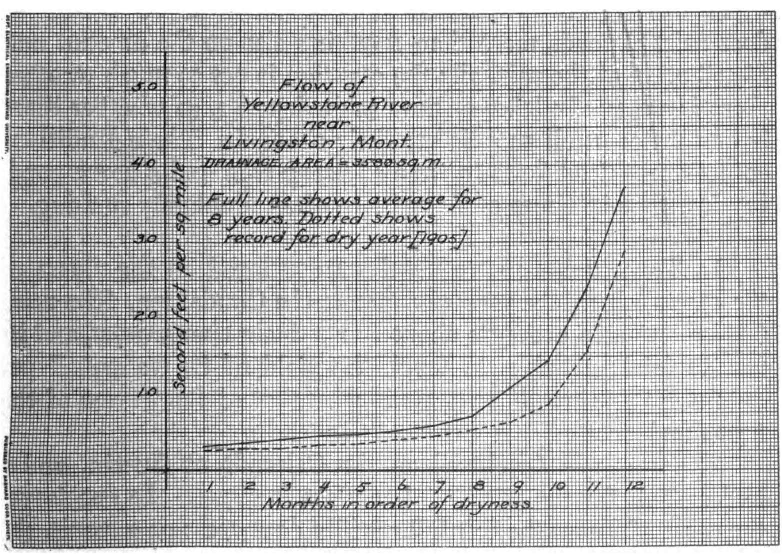
Of the rivers of Wisconsin, the Fox and the Wisconsin have been chosen for comparison. The former flows to Lake Michigan by way of Green Bay and the latter is a tributary of the Mississippi. As will be seen from the hydrographs shown, the run-off is remarkably uniform, no very excessive flows and few exceptionally low ones occurring during an average year. This uniformity is no doubt due to the steadying effect of Lake Winnebago and the lakes above, formed by the expansion of the Wolf and upper Fox rivers. The small yield is harder to account for, but it is believed that it is due to the underground escape of a large fraction of the rainfall, directly to Lake Michigan through the deep, permeable strata which connect the watershed and the lake.

The Fox is highly developed in the 35 miles from Lake Winnebago to Green Bay, the report of the Chief Engineer, U. S. Army, in 1897 stating that the total actual horse-power at that time was 31,898. The absence of great floods allows the construction of mills out into the stream and permits the building of spur tracks to plants on short trestles, only a few feet above the normal water level.

The Wisconsin flows south from the northern plateau to the Mississippi, and because of its location and size is preëminently the main river of the state. The drainage basin includes altogether 12,280 square miles, having an average width of 50 miles and a length of 225 miles. Its total descent is 1,046 feet in an estimated length of 429 miles, or closely 2.5 feet per mile. This, however, is largely concentrated in a few places, and so produces a number of valuable mill sites.

Comparison with the hydrograph of the Fox will show that the run-off per square mile of the Wisconsin is much the greater, although it, too, is uniform: not subject to excessive floods nor extremely low flows. This is an unusual phenomenon, as the drainage areas of the Fox and the Wisconsin are adjacent and receive practically the same rainfall, similarly distributed. At


Flow of
Guadalupe River
near Cuero, Texas.
DRAINAGE AREA = 5100 sq.m.
&
Colorado River
at Austin, Texas.
DRAINAGE AREA = 37,000 sq.m.
Second feet per square mile
0.5
0.4
0.3
0.2
0.1
Colorado: dryest of 5 years
Guadalupe: dryest of 3 years
1
2
3
4
5
6
7
8
9
10
11
12
Months in order of dryness.


Flow of
Yellowstone River
near
Livingston, Mont.
DRAINAGE AREA = 3580 sq.m.
Full line shows average for
8 years. Dotted shows
record for dry year [1905]
Second feet per sq. mile
5.0
4.0
3.0
2.0
1.0
1
2
3
4
5
6
7
8
9
10
11
12
Months in order of dryness.

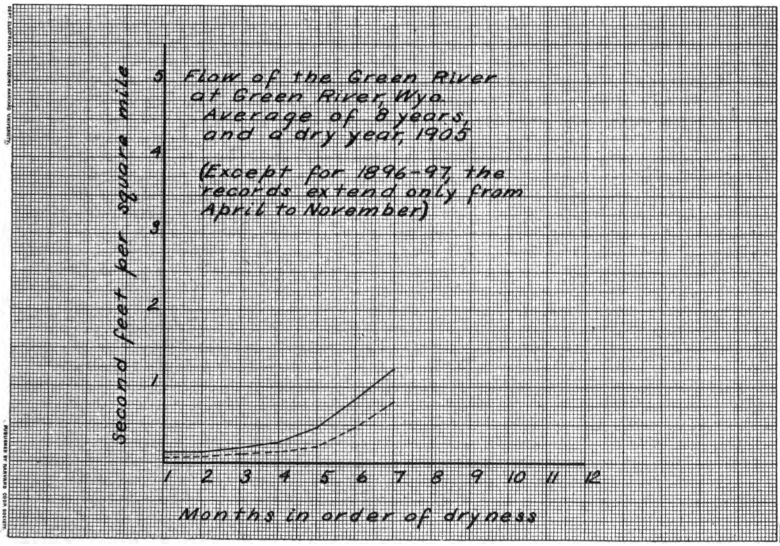
one place Fox River approaches within 1.5 miles of the Wisconsin, only a low marsh intervening, and even this marsh has a slope of three feet per mile toward the Fox. Levees at this and other places prevent the Wisconsin from overflowing into the Fox at times of high water. The probable cause of the small flow of the Fox has been mentioned.

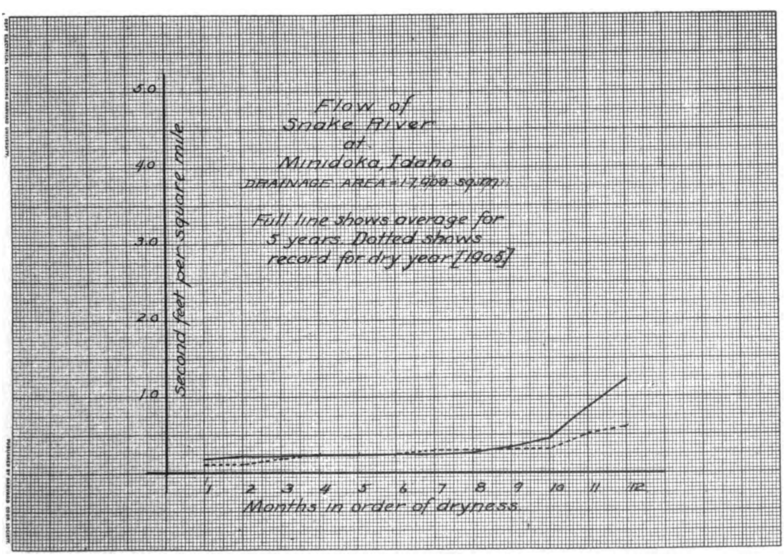
In the discussion of plans for artificial storage, the Wisconsin has probably received more attention than any other one river in the United States. The swamps and lakes at its headwaters, which already have a beneficial storage effect, can be readily improved so that the flow of the river can be more fully controlled. A few private interests have already constructed reservoirs in this district, and it is hoped that the government will lend its aid. The effect of such storage on the Wisconsin and other similar rivers of the state and of Minnesota would be noticeable in a decrease of the flood flows of the Mississippi.

The tributaries flowing to the Mississippi from the west present little if any power development possibilities near their mouths. In the mountains where they rise there are a number of developments, but by the time they reach the main river the water has largely evaporated or percolated. Such run-off as does exist depends more than anything else on the amount and distribution of the rainfall; the question is not so much whether there is storage in lakes or permeable deposits, as whether there is any water at all supplied to their channels. These conditions cause severe flood flows in time of heavy rain and a corresponding low flow in times of drought — often absolutely nothing.

In Texas, some power has been developed on the rivers of the coastal slope, the type of which is the Gaudalupe. The rainfall on its basin averages about thirty inches per annum, and its flow is fairly equable, although the yield of its watershed per square mile is small compared with that of the rivers of the north and east.

A power was developed on the Colorado at Austin, and a hydrograph for the river at that place is given. As one leaves the coast of Texas the rainfall rapidly decreases; as a result, the upper basin of the Colorado is an arid plain. This is reflected


Flow of the Green River
at Green River, Wyo.
Average of 8 years,
and a dry year, 1905
(Except for 1896-97, the
records extend only from
April to November)
Second feet per square mile
1
2
3
4
5
1 2 3 4 5 6 7 8 9 10 11 12
Months in order of dryness


Flow of
Snake River
at
Minidoka, Idaho
DRAINAGE AREA = 17,900 sq.mi.
Full line shows average for
5 years. Dotted shows
record for dry year [1905]
Second feet per square mile
5.0
4.0
3.0
2.0
1.0
1 2 3 4 5 6 7 8 9 10 11 12
Months in order of dryness

in its yield, which falls as low as 0.01 second foot per square mile. Occasional severe storms or "cloudbursts" fill the river for a few days, and give its flow a very flashy character.

The Rocky Mountains contain a large number of power developments, made possible by the high heads available, although the quantities flowing are usually small. These rivers are largely fed by the melting of snow on the mountain tops, which serves, in place of pondage, to equalize the flow.

The Yellowstone is one of the largest of such rivers; it flows from Yellowstone Lake into the Missouri River, and has a minimum monthly yield of 0.28 second feet per square mile, which, considering the low rainfall of 22 inches per annum on its watershed, is reasonably good. The summer floods are due to the greater rainfall, the occasional cloudbursts, and the fact that the snow is melting most rapidly at that time of year.

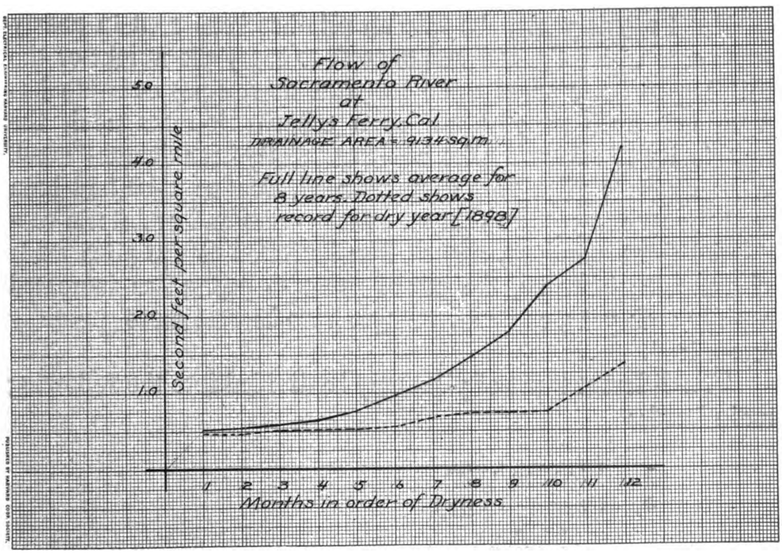
The Green River rises in about the same region, although not in a large lake, and flows south to the Colorado. Its drainage basin is thus in the mountains of Wyoming and a part of Colorado. The rainfall amounts to about 18 inches per annum, chiefly as snow in the winter months, and its flow is very flashy, falling to 0.05 second feet per square mile in November and December, while severe floods occur in the summer.

The Snake has nearly the same rainfall as the Green, but the flow is exactly opposite in type, being very equable. For nearly eight months of the average year the flow is nearly constant at 0.22 second feet per square mile, and the summer floods are not severe. With its large drainage area, 17,900 square miles, it should be an ideal river from a standpoint of uniformity of flow.

While the Sacramento River rises in the mountains, its flow is not affected as much by the melting snow as is that of the mountain rivers farther north. In its case the high rainfall in the mountains of California is the cause of its good flow. From a study of its hydrograph, it will be seen that its flow compares favorably with that of the Merrimac and the other good power streams of the East, while investigation into the rainfall statistics will show that in the valley the amount collected averages only 23.9 inches per annum, at Red Bluff. In the mountains,

however, from which the river flows, the rainfall is much greater: at Delta, the average of 14 years is 62.39 inches per annum; at Dunsmuir, for 10 years, 57.16 inches, and so on — all exceptionally high figures.

The tendency in California has been to develop the smaller streams, which provide high heads. On the Sacramento and its tributaries storage reservoirs have been constructed for use in




hydraulic mining and, to a less extent, for irrigation. The hydrograph shown is for the river at Jolly's Ferry, as computed from the records for seven years.

The Sacramento is characteristic of the rivers of northern California. Those flowing from the south, as the San Joaquin, have greater run-off and more severe flood flows.

## DISCUSSION OF VARIOUS PILES AND METHODS OF DRIVING THEM

BY FREDERIC W. SWAIN, '08

Until recent years, the wooden pile has been used in nearly every case where the soil was too soft to carry the weight of the building to be imposed upon it. But now, since concrete has come into such general use as a construction material, the superiority of concrete piles has successfully been demonstrated. When concrete piles were first invented, wooden piles had been used for so many years that many engineers and architects considered them standard, and at first hesitated to use piles made of concrete; however, the use of concrete piling has increased rapidly each year, as its advantages have become more generally recognized.

The different types of piles may be divided into the following main heads:

1. Wooden piles.
2. Concrete piles.
   - Method.
     - *a.* Molded.
     - *b.* Made in place.
   - Shape.
     - *c.* Tapered.
     - *d.* Uniform diameter.

*Wooden Piles.* — Owing to the fact that, unless wood is constantly kept saturated with water it will decay in a short period, the building laws of all cities require that wooden piles should be cut off at, or below, the level of the water table. Whenever this level is a considerable distance below the surface of the ground, deep and costly excavation, sheathing and pumping are necessary in order to carry the foundation down to the tops of the piles. Such a foundation, with its deep excavation, and the excessive amount of stone or concrete required for its con-

struction, is necessarily very expensive. There is a danger in cutting off wooden piles at the exact level of the ground water, due to the fact that frequently sewers or street drains are subsequently installed, or dams removed near the building, which may appreciably lower the level of the water table. Many buildings in Boston have been caught in this way, and before many years have passed it will be necessary to reinforce their present foundations.

Sometimes, under very heavy buildings, the whole area is filled with piles driven as closely together as conditions will permit. This is usually about two and one-half feet on centers.

FIG. 1.—"BROOMED" WOODEN PILES, SUPPOSED TO BE IN GOOD CONDITION, UNTIL EXCAVATED FOR INSPECTION

After the piles are cut off, a solid bed of concrete, into which the tops of the piles extend for perhaps six or eight inches, is laid over the whole area of the basement. To be sure, this practice ensures a rigid binding of the piles, but it gives an excellent opportunity for dry rot to take place in the wood which is embedded in the concrete. The bond between the concrete and the surface of the wood is very close and will permit little, if any, water to soak up into the top of the pile. Air, also, is largely excluded in the same way, and where these conditions exist dry rot is sure to take place before many years have passed.

In many localities the upper strata of the soil are fairly soft and are underlaid by a bed of stiff clay or hardpan. If wooden piles are driven in such soil no difficulty is encountered in driving through the soft material, but they are not sufficiently rigid to penetrate hard soil to any depth. Under these conditions the bearing power of the pile is limited nearly to its end support. The reasons for this are that the coefficient of friction between smooth wood and soft ground is low, that the frictional area of the pile is small, and that the compression of the soil, due to driving, is correspondingly small. Attempts to drive wooden piles into hardpan are attended with considerable danger of "brooming" the pile, and of course a "broomed" pile is worse than no pile. Many people claim that they know just what is taking place in the ground when a wooden pile is being driven, but such piles have frequently been exposed and found to be badly "broomed." When a pile is splintering in this way it apparently is in good condition because it is forced down under each blow, but instead of the point of the pile going deeper into the ground the fibers are merely buckling.

Specifications usually call for wooden piles not less than eight inches in diameter at the butt, and six inches at the point. Such a pile, having a small end area, small friction surface, and low coefficient of friction, necessarily has only a low carrying capacity. The customary loads for wooden piles range from about six to twelve tons, according to the length of pile and the condition of the soil. Even a four-story manufacturing building may be as heavy as fifteen tons per linear foot of foundation, from which it may be seen that a great number of piles would be necessary safely to carry the building.

No pile is safe unless it is driven vertically, and since it is seldom that wooden piles over twenty foot long are anywhere near straight, it is very difficult to drive them perpendicularly. If a pile is inclined to the perpendicular, its load is eccentric, which gives rise to serious stresses in the wood.

Wharf piles are subjected to alternate wetting and drying which, after a period of twenty years, will seriously decompose the wood. Other enemies of wooden piles in the water are the teredo and the limnoria, which honeycomb the pile and destroy it in a very few years. In the tropics this destruction takes place in about nine or ten months.

Wooden piles are driven usually either with a drop hammer or a steam hammer, the first being by far the more popular, because the energy of its blow is a definite quantity, whereas that of the steam hammer is somewhat uncertain.

*Concrete Piles.* — All types of concrete piles have the advantage of their point of "cut-off" being independent of the level

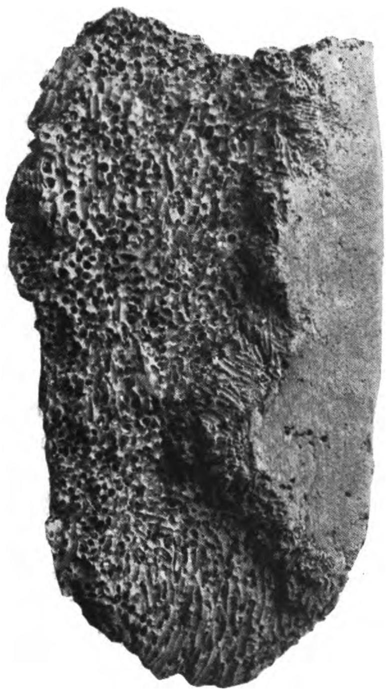


FIG. 2—SECTION OF WOODEN PILE, SHOWING THE DESTRUCTIVE WORK OF THE TEREDO AND LIMNORIA

of the water table; that is, they can be carried to any height desired. Most concrete piles have a much larger carrying capacity than wooden piles.

Concrete piles are considered by some to be a luxury. As a matter of fact, under many conditions, they are an economy, because, although the cost per linear foot of pile for concrete is considerably greater than that for wood, the saving in number

of piles, excavation, sheathing, pumping, foundation materials, and time of doing the work, far more than balances the greater cost of the piling itself.

*Molded Concrete Piles.* — Owing to the fact that there is so much handling necessary in the manufacture and installation of molded piles, the cost is comparatively high, but there are conditions where the molded pile is superior to other types, and is well worth the additional expense. One source of expense is the reinforcement, which is always necessary in molded piles, as protection against breaking in handling and driving.

Such piles are driven in three ways: With a drop hammer, a water jet, and a third method to be mentioned later.

Obviously it is unwise to use a drop hammer on a molded pile, because of the great danger of rupturing it.

The water jet is a safer method, but there is great danger of a larger hole being washed out than can be filled by the pile, hence the soil gives little or no lateral support to the pile. Not only is there lack of support in such a case, but there is also a lack of side friction. To be sure the coefficient of friction between smooth concrete and soft soil is not very great, but frequently it is surprising how much friction adds to the carrying power of the pile. When a pile is jetted down it is customary to tap it lightly with a hammer after jetting, to make sure that the end bearing is good.

The third method, and undoubtedly the most successful one of installing molded piles, is to drive by means of a drop hammer a heavy steel tube, fitted with an "alligator" point. This point, which is shown in the accompanying photograph, is similar to the "clam shell" dredge bucket, and is fastened to the bottom of the driving form by means of hinges, which allow the two sections to fall apart when the form is withdrawn. After the tube has penetrated to good bearing, a few cubic feet of concrete are deposited in the bottom of the form. Then a molded pile, slightly smaller in diameter than the inside of the driving form, is lowered into the form and forced into the plastic concrete. Then the heavy driving form is withdrawn, leaving the pile with a perfect end bearing and the necessary vertical support. The main advantage of this method lies in the fact that this driving form may be forced into stiff

clay or hardpan, whereas it is impossible to penetrate such material with a jet. This being the case, the pile merely rests on the surface of the hard stratum, and has but little support from the soft overlying stratum against lateral forces.

*Concrete Piles made in place.* — For the sake of clearness we will call the two principal systems installing this kind of pile No. 1 and No. 2. Briefly, No. 1 is as follows: A fairly rigid, collapsible, tapered core, about which is placed a thin sheet-iron shell, is driven to the proper penetration and then the core is collapsed and withdrawn, leaving the shell in the ground. In system No. 2 a heavy steel tube of uniform diameter, having a detachable cast iron point, is driven, then filled completely with concrete by means of bottom dump buckets, after which the driving form is pulled, leaving the cast iron point in the ground.

In system No. 1 the alleged object of leaving the shell in the ground is that concrete requires a form to keep out the water and protect it until it is set. It may be easily seen, however, that this shell is usually superfluous, because the compression of the soil about the pile itself constitutes a fairly rigid mold. As far as being sufficiently rigid to withstand the back pressure of the earth until the concrete has been placed is concerned, this shell is altogether inadequate. Besides, the use of a smooth shell appreciably reduces the friction force on the side of the pile.

When no shell is left in the ground, the surface of the concrete being very rough, a tremendous frictional value is obtained, which is capable of carrying a very large percentage of the load imposed upon the pile.

Piles made in place, if properly installed, have many advantages over other types in most soils. They are cheaper ordinarily than molded piles, because there is much less handling and less time required in installing them. Another advantage is that there is no possibility of injury to the pile in driving, as no concrete is placed until the form has been driven to the proper penetration.

In system No. 1 the concrete is shoveled into the form, which is bad practice, because the stone is very likely to separate from the sand and cement during the fall, thus giving an imperfect mixture.

Some people make the claim concerning system No. 2 that, since no shell is left in the ground to protect the concrete, the back pressure of the soil might squeeze the concrete, but the filling of the tube completely before the tube is drawn maintains a sufficient head of concrete in the tube to resist any possible earth pressure. In order to squeeze a pile in this way the back pressure of the earth must be great enough to lift the concrete bodily, and of course this condition is an impossible one.

*Tapered Concrete Piles.* — The following discussion applies to tapered piles, whether molded or made in place.

Most tapered piles have the following dimensions: For a twenty foot pile, a six inch point and twenty inch butt, and for a thirty to forty foot pile, an eight inch point and an eighteen inch butt. Since the volume per linear foot of the pile is greatest at the butt, the compression due to driving is correspondingly greater at the surface of the ground than at the point. The friction area, also, is proportional to the volume, and the result of these two facts is that a greater proportion of the load per linear foot of pile is carried at the top. But since piling is necessary, it follows that the top soil is not capable of carrying a heavy load, and yet a very large part of the load on the pile is carried by the top five or six feet. This obviously is wrong, because the poorest soil is made to carry the heaviest load, and the firmest soil at the lower end of the pile carries a comparatively light load, and is not fully developed, in as much as the volume per linear foot of the lower end of the pile and the frictional area there are much smaller than at the top.

An example, showing how incorrect is the use of piles with small points, is the method of building plain foundation walls. Such a wall always rests on a broad footing, and is wide at the bottom and narrow at the top. The reason for this is that it is necessary to distribute the load over the ground, and not concentrate it on a small area. No man would ever put in a foundation wall narrow at the bottom and wide at the top, and is it any more reasonable to put in piles in that manner?

The so-called "wedge action" in a tapered pile is a myth. To be sure, there is a slight upward component to the force exerted by the soil upon the pile, but this is small, and is negligible, because it is much less than the loss in frictional force due to the small volume of the end of the pile.

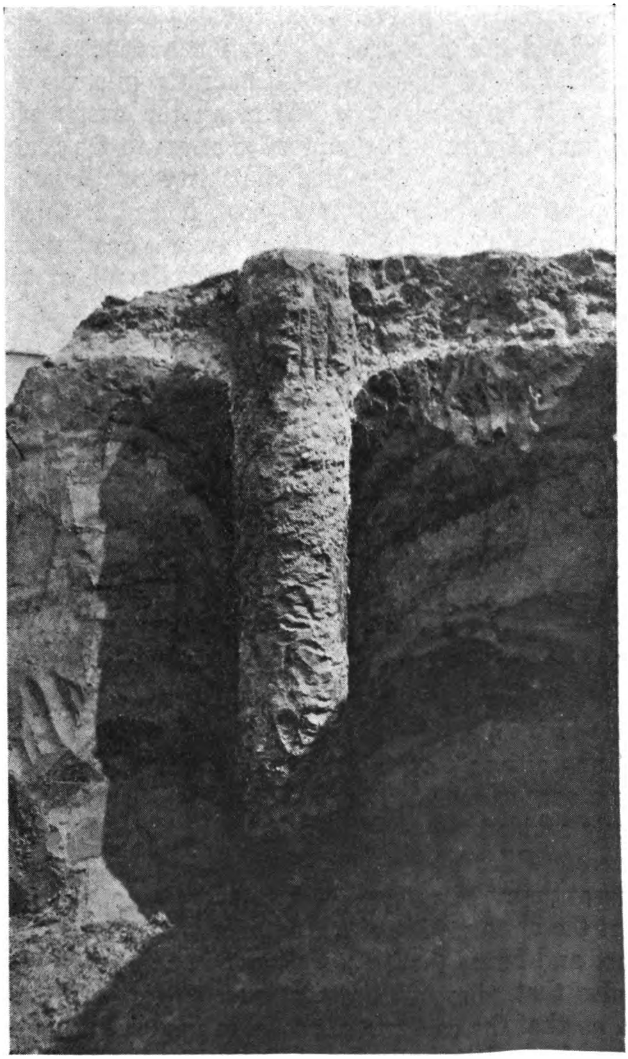


Fig. 3.—CONCRETE PILE, MADE IN PLACE, SHOWING LINES OF COMPRESSION

The shortest driving form for this type of pile is about twenty feet. It is easy to see that if only a ten foot pile is driven its cross section is very small, the top being thirteen inches in diameter, while the point remains six inches. Hence the volume and frictional area are very much reduced, and if the usual load of thirty tons is imposed upon the pile, the concrete will certainly be overloaded. Allowing the customary four hundred and fifty pounds compressive stress to the concrete, a pile must be at least one hundred and thirty-four square inches in cross section in order safely to carry a load of thirty tons. To be sure the area of a thirteen inch circle is one hundred and thirty-three square inches, but the section of the pile at the point where the load is carried is probably several feet below the top of the pile, and hence at a point where the cross section is very much less. This overloading of the concrete may be clearly shown if we take a definite example of conditions frequently encountered: if a tapered pile is driven through sixteen feet of soft top soil and then four feet into stiff clay or hardpan, practically the entire load is transmitted, without reduction, to the top of the hard stratum, hence the whole load must be carried on a cross section of concrete at most not greater than the area of a nine-inch circle, or sixty-three and six-tenths square inches. Now if this pile is carrying the usual load of thirty tons, on not more than sixty-three and six-tenths square inches of concrete, the load per square inch would be nine hundred and forty-four pounds, which is far in excess of that allowed by the building laws of any city in this country. This overloading of the concrete is a very serious matter, and is a condition which should be strictly avoided.

*Concrete Piles of uniform diameter.* — This type of pile has a great many advantages over a tapered one, among which are: that the cross section of a short pile is as great as that of a long one, and hence there is no danger of overloading the concrete; also that piles of this type very seldom have sheet iron casings, so that the concrete comes in intimate contact with the soil about it, and actually becomes cemented to it; and since the surface of the concrete is naturally very rough, a tremendous friction value is present; also that the frictional area per linear foot of pile, and the intensity of compression due to driving, are

constant throughout the length of the pile. The resistance of friction on such a pile increases steadily from nothing at the very surface of the ground to a maximum value at the point. This is the ideal condition, because the top soil, since piling is necessary in the locality, is not capable of carrying a heavy load, and the firmer soil, which is able to sustain a heavy load, is fully developed. If we disregard friction and consider only end bearing, the uniform diameter pile has a much larger point than a tapered one, because the diameter throughout the length of a straight pile is very nearly that at the butt of a tapering one. The diameter of the type of "uniform" pile, which has been used far more than any other system, is sixteen inches. Now compare the area of a sixteen-inch pile, 201 square inches, with those of six and eight-inch points of tapered piles. The area of an eight inch circle is one quarter of that area, or fifty and three-tenths square inches; and the area of a six inch circle is twenty-eight and three-tenths square inches, or less than one-seventh that of a sixteen-inch pile.

A steam hammer is sometimes used for pile driving, but the ordinary drop hammer is by far the more popular. The reason for this being that there is absolutely no uncertainty as to the energy of a blow struck by a drop hammer, if the weight of the hammer and the distance through which it falls is known, whereas a steam hammer may apparently be making very heavy blows when actually the blow is comparatively light.

This article has considered conditions as they actually occur in practice, and no theoretical assumptions have been made. Recently the subject of uniform diameter *versus* tapered piles has been widely discussed, but many of these articles have been based on theoretical conditions such as are never encountered in practice. Mathematical calculations and niceties cannot rigidly be applied to piles of any kind, because conditions of the soil vary very greatly, and no reliable coefficients for friction value are possible except for individual cases.

## A SLIDE RULE FOR CALCULATING HELICAL SPRINGS

The use of logarithmic scales as a means for making mathematical calculations dates from Gunter, who, in 1624, first used one scale in connection with a pair of dividers, the dividers being replaced by Wingate, later in the same year, by a second logarithmic scale. In 1671, Partridge gave the instrument, which we may now call a slide rule, very much the mechanical form which it now has, with the exception of the runner, which was added by Mannheim in 1851. This ordinary Mannheim rule, as it is called, has been improved in two directions, in regard to accuracy and in regard to rapidity of calculation.

Greater accuracy may be obtained by increasing the length of the rule, but in this way it soon becomes too long to handle conveniently, and so resort is had to circular or helical scales. Thus the Fuller rule has a scale 42 feet long, while Thacher's has one scale 30 feet and another 60 feet in length. Other rules attain a greater accuracy by having part of the scale on one line and the rest on a line below, and by having a lense in the runner. In 1851 it was even suggested to have a vernier for setting the slide.

For spring calculations great accuracy is impossible to obtain on account of uncertainty in regard to the data, and therefore, for the present purpose, the means of increasing the rapidity of calculation is of greater interest. Greater speed may be obtained if the number of factors which may be combined with one setting is increased. With the ordinary Mannheim rule the value of $\frac{a \times b}{c}$ may be obtained with one setting of the slide, using the lower or square root scales for greater accuracy. If the upper as well as the lower scales are used, such equations as $\left(\frac{a^2 \times b}{c}\right)^2$ and $\sqrt{\frac{a \times b}{\sqrt{c}}}$ may be solved with one setting. As early as 1899, a Frenchman by the name of Beghin published a description of a rule which, by means of a reciprocal scale,—that is, one running

from right to left where the others run from left to right,—made it possible to solve with one setting $a \times b \times c$ or $\frac{a}{b \times c}$. This principle of the reciprocal scale has been still further developed in the United States, by Cox, 1891, Thacher, 1901, and Rosenthal, 1904. Meanwhile in Germany, Schweth, 1901, devised a slide rule which, by the use of scales graduated to the logarithms of logarithms, enables one to find, for any number within certain limits, powers and roots with any whole, fractional, positive or negative exponent whatever.

Yet with complicated equations, the limit of speed can only be reached by means of rules specially graduated for the case at hand. Such rules have been in use almost as long as those for general calculations, but they are not as well known. D'Ocagne mentions, among others, the following :—

| Date | Inventor | Object of Calculation |
|---|---|---|
| 1741 | Camus | Capacity of a barrel |
| 1868 | Moinot | Stadia measurements |
| 1876 | de Montrichard | Cubic contents of wood |
| 1886 | Lebrun | Embankments |
| 1893 | Crevat | Weight of cattle |
| 1895 | | Speed of projectiles |
| 1897 | Gallice | Nautical measurements |
| 1903 | Leven | Stock market reports |
| 1904 | Mougnie | Flow of water |
| 1904 | Würth-Micha | Flow of steam |

This varied list may be extended from other sources, especially from the patent records. The following addition is from the United States patents:

| Date | Inventor | Object of Calculation |
|---|---|---|
| 1894 | Johnson | Load on columns |
| 1903 | Glaser | Weight and price of cloth |
| 1905 | Farmer | Wine or spirit calculations |
| 1907 | Hincks | Electrical measurements |
| 1908 | Hall | Columns and beams |
| 1908 | Nickel | Mean effective pressure |

Of the kinds of rules already mentioned, we find on the market to-day examples of those for stadia work, cubic contents,

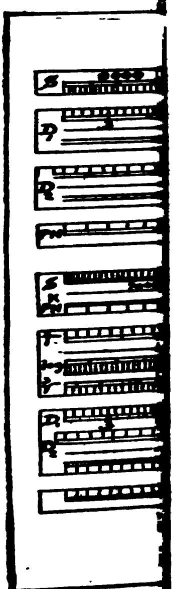
flow of water and electrical measurements, and there are in addition rules for calculating the horse power of an engine and for finding the main dimensions of hydraulic turbines.

A noteworthy collection of slide rules has been devised for use in connection with the Taylor system of shop management, comprising a speed rule, a gear rule, one to determine the proper feed and speed combination for machine tools, and another to calculate the power transmitted by belts, as described in various articles by Carl G. Barth in *Transactions A. S. M. E.*

It will be seen that a special rule may be used with advantage to solve any equation which is too time-consuming when solved by an ordinary rule, and the equations used in connection with helical springs are of this kind. The large number of variables makes the use of either tables or diagrams very inconvenient, since they must be too voluminous or incomplete.

The stress in a helical spring is due to the torsional moment $\frac{PD}{2}$, where P is the load on the spring, in lbs., and $\frac{D}{2}$ is the mean radius of the coil; that is, D is the diameter measured to the centre of the cross section of the wire, in inches. According to the original theory of Coulomb (which holds good for circular, though not for rectangular sections), if K is equal to the maximum stress in the wire, in lbs., per square inch, and $\frac{J}{c}$ equals the polar section modulus, in inches, then $\frac{PD}{2} = \frac{KJ}{c}$, and substituting the value of $\frac{J}{c}$ for a circular section of diameter $d$, in inches, we get $\frac{J}{c} = \frac{\pi d^3}{16}$ and $K = \frac{8\,PD}{\pi d^3}$.

If $f$ is the deflection of a spring, $m$ is the amount, measured by the arc at unit radius, that one section will turn with respect to another section situated a unit's length distant; and L is the length of wire in the active coils of the spring; then $f = \frac{mLD}{2}$. According to the older theory, which holds good for a circular section, if J is the polar moment of inertia, and G is the torsional modulus of



elasticity (which is approximately equal to $\frac{E}{2.6}$) then $m = \frac{PD}{2JG}$, or since in our case $J = \frac{\pi d^4}{32}$, we get $m = \frac{PD\,32}{2\,G\,\pi d^4}$, and substituting this value in our equation for $f$, we get finally $f = \frac{8PD^3\,N}{G\,d^4}$ since for all practical purposes L may be taken equal to $\pi$ DN, N being the number of active coils.

We now have two equations, $K = \frac{8\,PD}{\pi d^3}$ and $f = \frac{8PD^3N}{G\,d^4}$ which contain only two unknown quantities, D and $d$, if a probable value of G has been decided upon, and an allowable value of K assumed. As pointed out by Barth in patent No. 753840, we may change our equations to a more convenient form. If we substitute in the equation for $f$ the value of $P = \frac{Kd^3\pi}{8\,D}$, we get

$$d^4 = \frac{8ND^3Kd^3\pi}{fG\,8D} \text{ or } d = \frac{ND^2K\pi}{fG}$$

while we have directly from the equation for K, $d = \sqrt[3]{\frac{8PD}{\pi K}}$.

In *Zeitschrift des Vereins deutscher Ingenieure*, July 7, 1906, Proell goes a step further, deriving a formula for $d$ which does not contain D, by introducing the ratio $f/l$, $l$ being equal to $d$N. On the supposition that the spring is to be long enough to fill the available space, a suitable value for $l$, and hence for the ratio $f/l$, may be determined by considering that the total length of space occupied will be equal to about 1.1 N$d + f$ for a spring in compression, or about $1.1d(N+8)+f$ for a spring in tension, allowing four inactive coils at each end. Introducing the value $l = dN$ into Barth's equation for $d$ we get $\frac{f}{l} = \frac{\pi KD^2}{Gd^2}$, into which equation we may substitute values for $D^2$ or for $d^2$. From the original equation for K we have $D = \frac{Kd^3\pi}{8P}$, so that $D^2 = \frac{K^2d^6\pi^2}{64\,P^2}$, and substituting this value in our equation for $f/l$, we get

$$f/l = \frac{\pi^3K^3d^6}{64P^2Gd^2}, \text{ from which } d^4 = \frac{64fGP^2}{l\pi^3K^3}.$$

Similarly $d = \sqrt[3]{\dfrac{8PD}{\pi K}}, \quad d^2 = \sqrt[3]{\dfrac{64\,P^2\,D^2}{\pi^2\,K^2}}.$

$$f/l = \frac{\pi KD^2}{\sqrt[3]{\dfrac{64P^2D^2}{\pi^2\,K^2}}} \quad \text{from which} \quad D^4 = \frac{64f^3G^3P^2}{l^3\pi^5K^5}$$

As given by Proell the equations for D and $d$ are as follows:

$$d = \sqrt[4]{\frac{64G}{(K\pi)^3}}\ \sqrt{P}\ \sqrt[4]{\frac{f}{l}}$$

$$D = \sqrt[4]{\frac{64G^3}{(K\pi)^5}}\ \sqrt{P}\ \sqrt[4]{\left(\frac{f}{l}\right)^3}$$

The difficulty with any direct determination of values for $d$ and D lies in the fact that, in the end, we are forced to use some wire of standard diameter wound on a standard mandrel. Hence the calculated values of $d$ and D cannot be adhered to, and it is difficult to know whether the necessary changes in $d$ and D, which are made to conform to standard conditions, will produce changes in K and $f$ which may or may not be tolerated.

It is customary to call for a spring of a certain "scale," S, instead of mentioning the deflection, $f$. Since S equals the weight in pounds which will deflect the spring one inch, $f = P/S$, and substituting this value in our original equation for $f$, we get

$$S = \frac{G\,d^4}{8ND^3}, \text{ while, as already found, } K = \frac{8PD}{\pi d^3}.$$

These two equations are as simple as any which may be devised for calculating helical springs, yet D is raised to the third power in one equation, while $d$ is raised to the third power in one equation, and to the fourth power in the other. It was to save the labor involved in solving these two equations that I have been led to devise a specially graduated slide rule.

Fig. 1 shows a form of spring slide rule combined with a Mannheim rule for general calculations. P, N and K are read on the fixed scale No. 2, while S is given on the reciprocal scale No. 1. $D_1$ and $d_2$ are given on scale No. 6, and $D_2$ and $d_1$ on scale No. 7, the subscript 1 referring to diameters used in calculating K, while the subscript 2 refers to calculation of N. Scales No. 8 and 9 are

used for general calculations, the graduations being the same as on the square root scales of the Mannheim rule. Scales No. 3, 4, and 5, on the back of the slide, may be read from the back of the rule without inverting the slide, as is the case with the corresponding scales of the Mannheim rule. Scale No. 4 for finding the logarithm of a number is the same as on the Mannheim rule, while scale No. 3, giving the square root, and scale No. 5, giving the cube root, take the place of the scales for sine and tangent. It would of course have been possible to put scales No. 3 and 5 on the face of the rule, outside of scale No. 9, for example, thus leaving the back of the slide exactly as in the Mannheim rule, but as far as I have have been able to observe, thc sine and tangent scales are of little value, since whenever trigonometric calculations are required, results which may be obtained with a slide rule are not sufficiently accurate.

On scale No. 6 there is one arrow for scale $D_1$, and three arrows on scale $d_2$ marked 14, 12 and 10 respectively, signifying $G = 14$, 12 and 10 million, and on scale No. 7 one arrow serves for both $D_2$ and $d_1$. The use of these arrows is shown in the following rules for finding K and N with this rule.

*To find maximum stress in wire*, K.

1. Place runner at load, P, on scale No. 2.
2. Bring arrow on scale No. 7 to runner.
3. Place runner at diameter of wire, $d_1$, on scale No. 7.
4. Bring arrow on scale $D_1$ to runner.
5. The stress in wire, K, on scale No. 2, will then be opposite the mean diameter of coil, $D_1$, on scale No. 6.

*To find number of active coils*, N.

1. Place runner at scale of spring, S, on scale No. 1.
2. Bring arrow on scale No. 7 to runner.
3. Place runner at mean diameter of coil, $D_2$, on scale No. 7.
4. Bring an arrow on scale $d_2$ to runner.
5. The number of coils, N, on scale No. 2, will then be opposite the diameter of wire, $d_2$, on scale No. 6.

Although the number of movements required with this rule is less than with an ordinary rule, a still further reduction of movements and consequent increase of speed may be accomplished by

the use of the rule shown in Fig. 2, which is designed solely for calculating helical springs of round or rectangular wire. Wire of circular section is most economical in the use of metal, but a rectangular section is sometimes of service in giving the stiffest spring that will occupy a limited amount of space.

According to the older theory, from which the literature of springs is not yet free, if the cross section of the wire of the spring were a rectangle with width, $b$, and height, $h$, then using the same significance for other letters as before, we should have

$$\frac{PD}{2} = \frac{KJ}{c} = \frac{K(bh^3 + b^3h)}{6\sqrt{b^2 + h^2}}$$

As pointed out by Saint Venant in 1856, this formula does not hold good, and more recently Bach has found by experiment that Saint Venant's formulæ, which are at any rate too complicated for practical use, require slight modifications. I have therefore taken Bach's formula $\frac{PD}{2} = \frac{2\,Kb^2h}{9}$ and from this $K = \frac{9\,PD}{4\,b^2h}$. Then, if $b = d$ and $h = nb$, the stress in a rectangular section, where $b < h$, will be equal to the stress in a similar spring with round wire of diameter $d$, multiplied by $\frac{9PD}{4b^2h} \times \frac{\pi d^3}{8PD} = \frac{.883}{n} = A$.

Values of the ratio, A, for various values of $h/b = n$ are given in the following table:

| $n$ | A | B | C | D |
|---|---|---|---|---|
| 1.00 | .883 | 8.05 | 7.12 | 1.27 |
| 1.25 | .707 | 7.97 | | 1.95 |
| 1.50 | .589 | 7.90 | | 2.68 |
| 1.75 | .505 | 7.82 | | 3.45 |
| 2.00 | .441 | 7.75 | 7.00 | 4.21 |
| 2.25 | .393 | 7.67 | | 5.00 |
| 2.50 | .354 | 7.60 | | 5.78 |
| 2.75 | .322 | 7.52 | | 6.58 |
| 3.00 | .295 | 7.45 | | 7.39 |
| 4.00 | .221 | 7.15 | 6.70 | 10.75 |
| 5.00 | .177 | 6.85 | | 14.32 |
| 6.00 | .147 | 6.55 | | 18.15 |
| 8.00 | | | 6.40 | |

Authorities also disagree in regard to the deflection of a spring of rectangular wire. The value of $m$ in the formula $f = \frac{mLD}{2}$ would be, according to the older theory, $m = \frac{3PD}{2G} \frac{(b^2 + h^2)}{b^3h^3}$, in which, according to Bach, the factor $3/2$ should be replaced by $B/4$, and the values of B should be obtained from the equation $B = 8.35 - .3n$. In column B of the table are values computed from this equation, and in column C the corresponding values calculated by Saint Venant. Adopting the values of Bach,

$$f = \frac{B\pi NPD^3}{8G} \frac{(b^2 + h^2)}{b^3 h^3}, \text{ from which } S = \frac{8\,G\,b^3\,h_3}{B\pi ND^3(b^2+h^2)}$$

for a rectangular section, taking the place of the formula for a circular section, $S = \frac{Gd^4}{8N\,D^3}$. Since $h = bn$ and $b = d$ as before, the scale of a spring of rectangular wire will be to the scale of a spring of round wire in the ratio $\frac{64\,n^3}{B\pi(1+n^2)}$, values of this expression, for various values of $n$, being given in Col. D of the table. Thus by the use of Cols. A and D of the table, it is possible to calculate helical springs of rectangular wire with the rule shown in Fig. 1. Such springs may, however, be calculated by means of the rule shown in Fig. 2, without the use of the table.

The form of rule shown in Fig. 2 has two slides and requires no runner. P and N are read on the fixed scale No. 6, and S and K on the other fixed scale No. 1. $D_1$ is on the scale No. 2 and $d_2$ on scale No. 3, and scale No. 4, in two sections graduated alike, is for $D_2$ and $d_1$. The scales shown in Fig. 1 for general calculations are here omitted, since the rule is intended solely for calculating helical springs. Scale $D_1$ and $d_2$ are both supplied with arrows, that on $d_2$ being marked 12 where it extends to scale No. 2. This latter scale shows graduations from 4 to 15, representing values of G, the graduation marked with the arrow standing for 12,000,000, the value of G most commonly used for steel. When G has some other value, the proper graduation of scale No. 2 is to be used in place of the arrow on scale $d_2$ and in the same manner. On scale No. 4 are two arrows marked respectively $d_1$ and $D_2$, which are to be used for springs of round wire. When, however,

the wire has a rectangular section, with side $h$ greater than, or equal to side $b$, the proper graduations on scale No. 5 are to be used in place of the arrows, taking $d_1$ and $d_2$ equal to $b$.

In order to find the stress in wire, K, we may proceed as follows:

1. Place the arrow marked $d_1$ (or a graduation to the right of it on scale No. 5) opposite the load on scale P.
2. Place the arrow on scale $D_1$ opposite the diameter of wire on scale $d_1$.
3. The stress in wire, K, will then be opposite the mean diameter of coil on scale $D_1$.

The number of coils required for the given scale of spring may then be calculated.

1. Place the arrow on scale $d_2$ (or a graduation on scale No. 2) opposite the scale of spring on scale No. 1.
2. Place the arrow marked $D_2$ (or a graduation on scale No. 5 to the left of it) opposite the diameter of wire on scale No. 3.
3. The number of coils, N, will then be opposite the mean diameter of coil on scale No. 4.

The saving in time from the use of the special rule is shown by the fact that in solving for either K or N only two movements of the slides are required, while with a Mannheim rule three movements of the slide and two of the runner are needed to find K, and at least four of the slide and three of the runner to find N. Allowing for extra settings of the runner for convenience in reading, and for the possibility of having to shift the slide to the other side of the runner, it will be found that six movements of the slide and seven movements of the runner might be needed to find N. But the reduction in the number of movements does not represent the entire saving of time. With an ordinary rule the decimal point has to be determined by a separate calculation, which is often the most troublesome and time-consuming part of the whole operation, but the decimal point is given in the answer as read from the special rule.

WINSLOW H. HERSCHEL.

## THE CONSTANT CURRENT MERCURY ARC RECTIFIER

BY CHARLES J. MUNDO, '07

A field of usefulness for the constant current mercury arc rectifier exists because of (*a*) the advantage of high voltage alternating current transmission and distribution, and (*b*) the superior efficiency and light distribution of direct current arc lamps, especially the magnetic lamp with its low energy and maintenance costs.

A common type of the C. C. mercury arc rectifier set is connected to a constant potential alternating current source as shown in Fig. 1. The set consists essentially of the following parts:

(*a*) A constant current transformer.
(*b*) A direct current reactance.
(*c*) An exciting transformer.
(*d*) The rectifier tube.

*Transformer.*— The transformer is of the usual constant current type, consisting of a three-legged laminated magnetic core, the middle leg of which is surrounded by two flat secondary coils fixed in position, and by a primary coil suspended on a rocker arm. This coil is counterbalanced partly by weights and partly by the electrical repulsion between coils. The primary coil is free to move up and down the core, the limits of load voltage regulation being determined by the limits imposed by the length of the core on the movement of the primary coil with respect to the secondary. This voltage range is generally from full load to one-third.

Under operating conditions the position of the primary coil depends on the voltage required to force the secondary current through the resistance of the load circuit. A decrease in the resistance of the secondary circuit momentarily allows a higher current to flow, the repulsion between coils increases and the primary assumes a position of equilibrium at a point such that

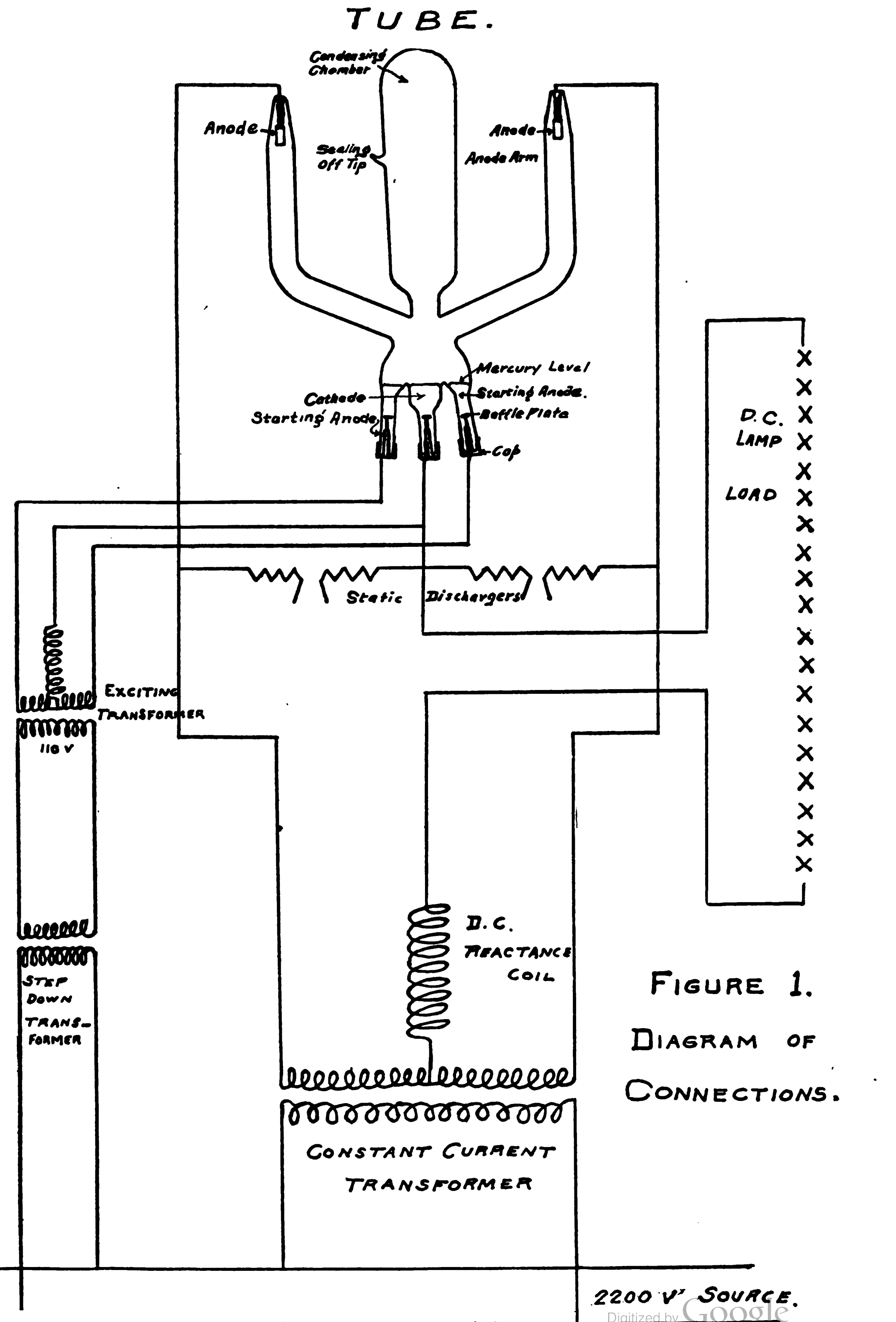



FIGURE 1.
DIAGRAM OF CONNECTIONS.

(because of greater flux leakage) the lower e.m.f. now generated in the secondary supplies the normal secondary current to the circuit.

The transformer supplies an alternating voltage to the tube for rectification. By means of counter-weights and adjustment of the sector arms of the primary coil suspension system, the transformer is regulated so that throughout the range of load variation, the rectified current has a constant value of four amperes. It is then found that the transformer secondary supplies to the anodes a current departing very slightly, as described later, from a constant r.m.s. value. The voltage supplied to the tube depends on the number of lamps in the load circuit.

The transformer also serves the valuable purpose of insulating the source from the arc lamp circuit.

*D. C. Reactance.* — From the middle point of the transformer secondary coils a tap is brought out for the connection of the reactance, or direct current reactive coil. This is a low resistance coil made up on a laminated magnetic core with an adjustable air gap. The coil is placed in circuit with the lamp load, and is excited by the periodic variations in the rectified current, (*d*) Fig. 2.

The lamp supply voltage must not fall below the back e.m.f. of the arc, and as the ohmic resistance in the load is small the permissible variation from the mean is in the neighborhood of 10 per cent. By storing up energy when the rectified voltage is high, (*c*) Fig. 2, and returning it when the voltage is low, the D. C. reactance minimizes these variations. The rectified current, (*d*) Fig. 2, will vary more than 10 per cent from the mean value because of the negative temperature coefficient of the lamp arc.

*Exciting Transformer.* — The exciting transformer consists of one primary, two secondaries in series, and a reactance coil tapped on the middle point of the secondaries. The primary is excited through a step-down transformer from the main line, or otherwise. The secondaries are connected to the mercury starting anodes of the tube, Fig. 2, and the reactance to the cathode. The function of the exciter is to supply power for (*a*) starting the tube, and (*b*) the operation of an independent arc between

the starting anodes and the cathode. This arc maintains ionization and insures the restarting of the main arc should the tube go out for any reason.

*Tube.* — The tube, Fig. 1, is exhausted to a high vacuum and sealed off at the tip, the vacuum being necessary for the unimpeded flow of current. When the set is put into service the tube must be operated with its load short-circuited long enough for the heat to drive all mercury from the anodes. Whenever the tube is started with the mercury on either anode, or the metal is deposited during operation, a cathode spot is likely to form on the anode and arcing to the other take place, resulting in the destruction of the tube.

The anodes are made either of graphite or iron, and are electrically connected to and held in place by platinum leading in wires.

The cathode, consisting of cap, leading in wires, seal, and iron baffle plate, is filled with mercury, as are the starting anodes. The latter have the same essential construction as the cathode. The baffle plate serves the purpose of protecting the glass seal from mercury when the tube is turned from an inverted position.

The production of the conducting vapor takes place at the surface of the cathode at what is known as the cathode spot. The wandering of this spot is explained by the fact that vaporization takes place most easily from a point or ridge. A depression in the mercury surface is made by the vapor that is constantly being projected out from the cathode spot. The spot continually tries to climb up to the edge of the hole, and in pursuit of this object wanders over the cathode surface.

The spot may go over into a starting anode because of a faulty tube, or because of arcing grounds on the positive side of the line. The tube may start up with the spot in a starting anode. The exciting transformer would eventually be burned out if the tube were allowed to operate long with the spot in the starting anode, for it will be seen from Fig. 1 that the exciter secondaries would carry the load current. In practice a pilot lamp is employed to indicate normal tube operation. This lamp goes out if the spot goes over, or if the tube ceases to operate. The spot may be returned to the surface of the cathode by shaking the tube.

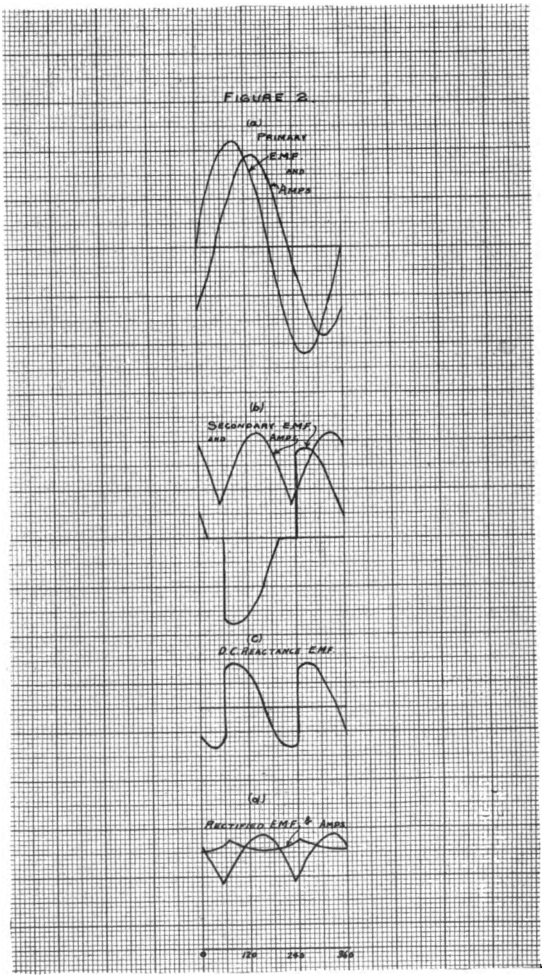
*Operation.* — The operation of the rectifier tube is based on the production of negatively charged ions at the cathode spot. These can be deprived of their charges only at a positive electrode. The necessity for the use of two anodes in attaining the full utilization of the current wave will be understood if it is seen that two anodes, when connected to the alternating voltage from the transformer secondary, become alternately positive to a cathode connected to the neutral point of the secondary. As there exists in the tube no means of producing negative ions at the anodes, current passes in one direction only in the arc stream. The uni-directional passage of current is not a property of the mercury vapor (which under ordinary circumstances is not a conductor at all) but is a result of the employment of an ion producing cathode and anodes which do not produce negative ions but merely relieve such ions of their charges. Should an ion producing spot, or cathode, be established accidentally on either anode current would pass, or arcing take place, from one anode to the other as already described.

The tube is started by shaking it (with a handle provided for the purpose) so as to make electrical connection through the mercury between the cathode and either starting anode. An arc is drawn when the mercury stream is broken. Vaporization and ionization take place, and current is carried alternately from each starting anode to the cathode. This arc once established current is immediately drawn alternately from the main anodes to the cathode. From the latter it passes uni-directionally through the load circuit to the reactance and to the neutral point of the transformer secondary.

The vapor blast at the cathode must be continuous, as any interruption, however momentary, of the ion supply will cause the tube to go out. As an alternating voltage, (*b*) Fig. 2, is supplied to the anode arms the arc would go out every time the current wave passed through zero were it not for the D. C. reactance, the impedance between the secondaries and primary, and the impedance between the secondaries of the C. C. transformer. These three factors contribute to overlap the current waves from the anodes, (*b*) Fig. 2, and thus insure the continuous operation of the tube. The rise of the anode current is delayed and the energy taken up in back e.m.f. on the rise is

restored on the decline so that each half wave has a duration somewhat longer than 180 degrees, the rise and fall resembling the familiar exponential curves.

The anode e.m.f., (*b*) Fig. 2, is shown as having nearly zero value during the overlap of the current waves. The overlap




throws the two halves of the transformer secondary in parallel during the instant when the load is being transferred from one half to the other. On the breaking of one arc the voltage imme-

diately jumps to its normal instantaneous value. In Fig. 2 no attempt has been made to give the actual curves as taken by the oscillograph, the general shape merely being shown.

The rectified voltage curve is shown at (*d*) Fig. 2. The effective load voltage is somewhat less than half the voltage supplied by the transformed secondary, the ratio having a general average value of .38 at full load. There is a loss in the D. C. reactance and a slight loss (25 volts) in the tube. It must be remembered, however, that only one-half of the full secondary voltage is available at a time for tube operation, and that the a. c. voltage is read on an instrument which indicates the square root of mean square, while the d. c. instrument (D'Arsonval type) reads the mean value of load voltage.

As the arc lamp load decreases the voltage ratio falls and the current ratio rises. As the rectified amperes have a constant mean value, the transformer, to compensate for the rise in current ratio, must supply the anodes with a slightly falling current.

In the tube, independent of load, there is a drop of about 25 volts. The chief heating is at the cathode and the anodes.

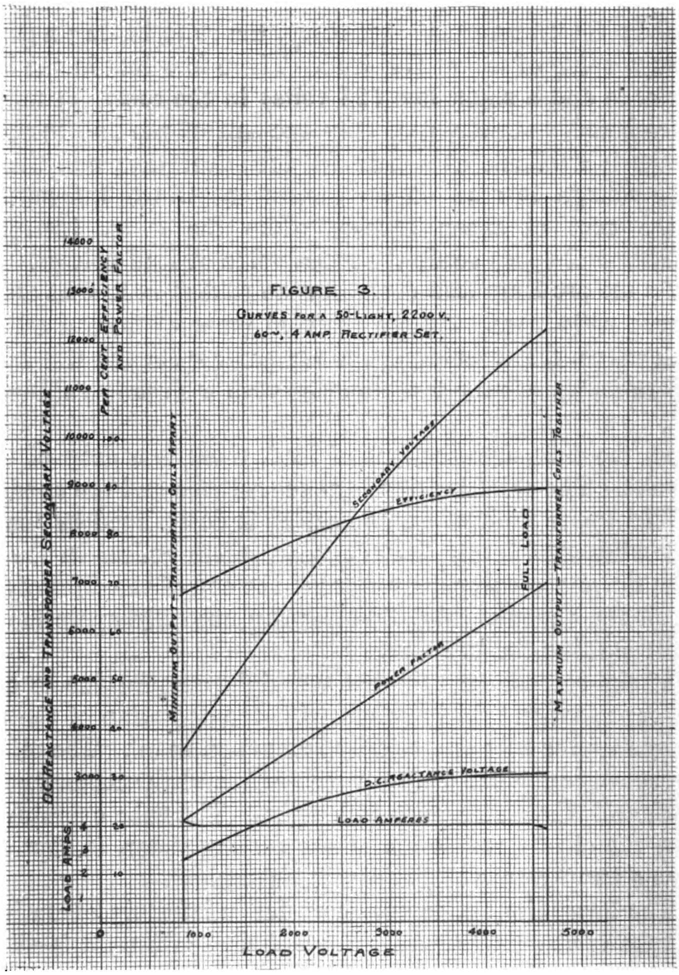
The upper limit of anode heating is determined by the fact that, when sufficiently heated, gases which collect in the arm above the anode will expand beyond the end of the electrode and cut off the vapor supply, first causing unsteady operation and finally putting the tube out.

If the cathode gets too hot the high pressure due to excessive vaporization will interfere with the operation of the tube. In practice the tube is cooled by immersion in oil. The oil tank is generally provided with a water coil, and thermometer wells for the oil, the water inlet and outlet. The tube operates best when the oil, by regulation of the cooling water, is kept at or below a temperature of 90 degrees Fahrenheit.

The lower limit of temperature for satisfactory operation of the tube is about 50 degrees Fahrenheit. If the oil is allowed to get below this temperature static discharges at starting may occur between the anodes and the cathode, especially in old tubes. The tube is protected, Fig. 1, by static discharges, with resistances in series with the gap.

The tubes have an average life of over 500 hours, many stations averaging over 1,000 hours. Some tubes have operated

more than 5,000 hours. When through deterioration a tube gives unsatisfactory service its life may be appreciably prolonged by the use of the *static protector*. This device consists of a light, metallic, bell-shaped cap which fits over the end of the




anode arm and is insulated by an asbestos web from contact with the glass. Accumulated gases in the tube, which are taken up by the anodes during rest, are driven out by the passage of a current wave when the tube is started. The static charge of the

anodes holds these gases in a thin cushion which prevents the passage of the next current wave, and operation of the tube. The use of the protectors is based on the theory that no static charge can exist within a perfect conductor. The gas cushion is deprived of its means of support by placing the bell-shaped conductors down over the anode arms. The protector is supported by the asbestos web and electrically connected to the anode leads after the latter have passed through the short glass tube which separates the protector from the anode arm.

*Characteristics.* — The curves, Fig. 3, are intended to show the characteristics of the set under load ranging from minimum to maximum outputs. They were taken on a 50-light, 2200 volt, 60 cycle rectifier set which delivered four amperes to a load of magnetite arc lamps.

The regulation, efficiency, and power factor of the set are practically that of the C. C. transformer.

The energy expended in the tube is about 0.5 per cent of the full load output. The efficiency of the reactance is high because of its low resistance. Its core losses are proportional to $2\ n$ and $.141\ I$, for a 25 per cent rectified current variation, where $n$ is the frequency of the supply circuit and $I$ is the mean rectified current; but the core losses are insignificant, the total losses in the reactance being less than 1 per cent. The exciting transformer consumes about 100 watts independent of the size of the set. The full load efficiency of the set will be in the neighborhood of 90 per cent, and it will be seen from Fig. 3 that the efficiency is quite high throughout the range of operation. The full load power factor will range from 65 to 70 per cent.

The rectifier set has no revolving parts. It requires a minimum of station floor space, and little attention. No harm can result in case of a short or open circuit on the lamp line, the C. C. transformer protecting the set from both these contingencies.

# CLIPPINGS

## TRAIN LIGHTING AT 110 VOLTS BY TURBO-GENERATOR ON LOCOMOTIVE

"Suburban train operation, differing from through train operation in that there is no changing of locomotives and rarely of cars from one end of the run to the other, offers exceptional opportunity for simplicity in electric train lighting. This fact is amply demonstrated by the new equipment adopted as standard by the Chicago, Burlington & Quincy Railroad in its suburban service out of Chicago. The arrangement has been tried on one train making a regular daily run in the evening from Chicago to Aurora, a distance of about 40 miles. It consists simply in placing a turbo-generator on the locomotive with electrical connections to the cars.

"The generating outfit consists of a horizontal Curtis turbine directly coupled to a two-pole, 20 k.w., 110-volt d. c. dynamo. The whole unit is ironclad, the covers being clamped in with gaskets, so that it is stormproof. Steam is taken at the locomotive boiler pressure on different classes of engines, running from 140 lb. to 180 lb., the variation being entirely taken care of by the governor. The turbine turns at 4500 r.p.m. The whole unit is 5 ft. 6 in. long, 2 ft. 8 in. high, and 1 ft. 11 in. wide. It weighs 2,300 lb., and is securely bolted on top of the shell of the locomotive boiler.

"There is a marble panel in the cab of the locomotive on which are mounted a voltmeter and a rheostat. Ordinarily all the attention that is needed to operate the train-lighting set is for the fireman to open the steam valve when he wishes to put the turbine in operation and close it when the run is over, but should the number of cars in the train vary (although this is ordinarily not the case) the difference in resistance on the dynamo circuit, as indicated by the voltmeter, is met by manipulating the rheostat.

"From this locomotive unit nine standard suburban passenger coaches are lighted and also the headlight and lamps in the locomotive cab. The locomotive headlight is a 50-cp carbon-filament stereopticon lamp, arranged with the usual reflector,

and is said to give six times as much light as the oil lamp which is usually used on suburban service. In the cab there are four electric lamps arranged to illuminate the gages or placed on lamp cord so that they may be used anywhere about the cab or in the tender if needed.

"The lamps used throughout for car lighting are rated at 16 cp. There are nine cars, as stated, and each one has 21 lamps. Four of these are on the platforms, one is in the toilet room, and 16 are placed in the body of the car underneath the deck sash."

Gibbs connectors are used between cars. The lighting unit on the locomotive does not make an appreciable demand on the boiler. — *Electrical World.*

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The program for reconstruction of the Spanish navy involves the building of three heavy-armored vessels of 15,000 tons displacement, three 350-ton destroyers, or three submarines, and twenty-four torpedo-boats. — *International Marine Engineering.*

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## WIRELESS IN JAPAN

According to a consular report nearly all Japanese steamships on foreign lines are furnished with wireless telegraphy. In the navy all ships, from battleships down to torpedo-boat destroyers, are equipped with wireless telegraphy, and the wireless telephone was successfully used at the grand naval review off Kobe last autumn. The wireless telephone is being developed in the communication department and in the navy. The Teishinsho system of wireless telegraphy used has been developed in Japan and is stated to differ from the Marconi and De Forest systems. — *Electrical World.*

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The Trans-Andean Railway, which has been projected from Arica, Chili, to La Paz, Bolivia, has been put under contract. The line is to be about 300 miles long, and will reach an elevation of about two miles above sea level. Part of the line will lie through a desert between the Andes and the Pacific, over which the contractors propose to lay a water supply system for use during construction. The mountainous section requiring the heaviest construction will be about 50 miles long. The traffic between La Paz and the sea is now carried by pack trains. — *Engineering Record.*

## A 6600-VOLT SINGLE-PHASE RAILWAY

A 77.5-mile, single-phase railway has been placed in operation between South Bend, Ind., and Pullman, Ill. The line is known as the Chicago, Lake Shore & South Bend Railway. The rolling stock at present consists of 48 passenger cars, 12 flat cars, 1 snowplow, and 1 utility car. Each of the larger passenger cars is equipped with four 125-hp Westinghouse single-phase motors arranged for multiple-unit control. Along the main portion of the route use is made of a trolley e.m.f. of 6600 volts, but through the cities and in the shop and yards the trolley e.m.f. is lowered to 700 volts. In each case single-phase current is utilized, no direct current being employed. Thus the control equipment retains the simplicity of the single-phase outfit. The trolley wire is of No. 4-0 groved section supported by a ½-in. steel catenary cable. There are ten sub-stations. Two are at the terminals of a 33,000-volt transmission line and eight are used for supplying energy at low tension in the city section and in the car shops near Michigan City. The cars are provided with both wheel and pantograph collectors; the latter is used only at 6600 volts, while the former can be operated at either 700 volts or 6600 volts.

---

The longest concrete arch so far attempted is the 280-ft. span of the 708-ft. concrete bridge now being built to carry Detroit Avenue over Rocky River at Cleveland, Ohio. The bridge comprises the main arch, with a span of 280-ft., approached on one side by two and on the other side by three 50-ft. arches. It has a 40-ft. roadway and two 8-ft. sidewalks, and is designed to carry on two tracks 60-ton electric cars. The main arch consists of two ribs, 34-ft. c. to c., each 18-ft. wide and 6-ft. thick at the crown, and 22-ft. wide and 11-ft. thick at the spring. No reinforcement is used in the arch ribs proper, but the floor system, which is carried upon spandrel columns and arches, is reinforced with I beams. — *Engineering News.*

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The first lot of 300,000 concrete railway ties used by the Italian State Railways proved so satisfactory that a similar lot has been ordered. The ties cost $1.48 each in Italy. — *Engineering-Contracting.*

# HARVARD ENGINEERING JOURNAL

A QUARTERLY

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Published four times during the college year by the Board of Editors of the Harvard Engineering Journal.





**Subscription Rates**

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| Per year, in advance . . . . . . . . | $1.00 |
| Single copies . . . . . . . . . . | .35 |

Address all communications:—

HARVARD ENGINEERING JOURNAL,
Room 218, Pierce Hall,
Cambridge, Mass.

Entered at the Post Office, Boston, Mass., as second-class mail matter June 5, 1902.


## CHANGE IN COURSES FOR 1909-10

Owing to the appointment of Professors Swain and Clifford to the Faculty of the Graduate School of Applied Science, the courses in civil and electrical engineering have been, in part, re-arranged. The revised list of courses will be found in the annual announcement of courses, published by the university.

## ENGINEERING SOCIETY

April 14, Dr. Charles P. Steinmetz, consulting engineer of the General Electric Company, and Professor of Electric Engineering at Union University, gave a most interesting talk on the history of the development of power transmission. Attempts to transmit direct current have been abandoned, and alternating currents, single and polyphase, have come to be the most economical and satisfactory method of transmission. There have been great changes in the design of the generator machines, and many changes in the frequency produced, covering a range of from 20 to 120 cycles per second, with a general tendency now of 60 cycles for general utility and 25 cycles for power purposes. The voltages used have made enormous strides from 2500 up to 40,000 volts, and some even having been successful at 110,000, or even higher. The trouble encountered with these high voltages is not with the voltages but the construction of the transmission line and the insulation.

The distances over which electric power is transmitted have increased up to 100 to 400 miles. There was a tendency at one time toward large central developments and long distance transmission, taking place of the old system of smaller power stations. This was due generally to the fact that larger electric plants could be located only at certain places. A further development has produced a system by which several central stations are linked together in a network of transmission lines, there being main trunk lines, from which the distribution lines and systems are taken at the required places. This has worked very successfully in Southern California. This method makes it possible for the loads on the system to be more easily balanced. All the central stations feed into the main trunk line and each helps to share the loads. The trunk lines are of very heavy and costly construction, every effort being made to make the insulation perfect and the line permanent.

May 6, Mr. Frederic W. Taylor, Consulting Engineer and past President of the American Society of Mechanical Engineers, spoke on "Success in Engineering." The difference between success in college and that after graduation lies in the difference between the conditions under which one works. Its student is

absorbing principles and facts, wholly for his own benefit and his success as a student depends only upon himself. The graduate is in a different position; he must serve and please his employer, carry out all orders, and do somewhat more than has been asked; otherwise he fails. The employer pays his men for doing what he wants done. It must always be remembered that he wants results, and not reasons, why one does not succeed. Of course an employer has no right to request that a mean thing be done, and one should not do it, not only because it is wrong, but also because it does not pay.

Numerous anecdotes from the lives of men who have succeeded were suggestive of ways in which to succeed. One must have hope and ambition enough to take a step forward of one's present position. Inventions may be made, but unless they are real improvements over machinery already in use they should not supersede the old. In engineering, that design or undertaking which saves money is the one which is appreciated to a large extent, and so this also is a factor in success.

The education which the student gets should be just that little which decides between great success and partial success; but brains alone will not pull one through. They must be accompanied by commonsense virtues and the ability to accomplish any task.

June 1, 1909, the following officers were elected for next year: President, W. B. Strong, '10; secretary, H. Nawn, '10; treasurer, I. A. Blake, '10; graduate secretary, A. R. Arellano, '09; adviser, Professor I. N. Hollis.

## CIVIL ENGINEERING CLUB

May 25, 1909. The last meeting of the year was held in E. L. Lincoln's room, Matthews 37. The speaker of the evening was Mr. Howard M. Turner, '06, who is with the Turner Construction Company of New York. His subject was "The Stadium." He confined himself to the present additions which are being made, and described the problem of carrying on the construction of the colonnade. The design and location of the mixing plant and the economical handling of materials are considerable problems in themselves. The handling of the forms

also required careful consideration. Numerous sketches and photographs showed the details of the forms, the twisting apparatus and the methods of doing the work. This talk by Mr. Turner proved not only interesting, but also very valuable, since he brought out clearly the fact that the economical construction of any design requires as much thought as the design of the structure.

At this meeting the following officers were elected for the coming year: President, George W. Lewis, '10; secretary, Adolph R. Arellano, '09; treasurer, W. H. Durfee, G.S.

---

## TRADE NOTE

The accompanying illustrations show two 24-in. x 18-in. Jeffrey Contact-lip Pivoted Bucket Conveyers runing in planes at right angle to each other. Both these conveyers run at a speed of fifty feet per minute, and are capable of handling, normally, fifty tons of coal per hour. The first conveyer in the coal storage house of the plant is a "run-around," with 104 feet of horizontal, and 43 feet of vertical travel; the lower horizontal run being in a concrete tunnel beneath the storage house floor, and the upper horizontal run in a monitor above the roof of the building. Power is furnished by a 14 horse-power steam engine, located in the tunnel.

The route of the coal as it is handled by this equipment is in brief as follows:

Railroad cars are shunted into the storage building, and dump into a steel track hopper twelve feet square, from which the coal passes to a double-headed flight conveyer of sixteen-foot centers. This conveyer is driven through a chain and jaw clutch from the take-up, and, carrying the coal up an incline of thirty degrees, discharges it into a 24-in. x 30-in. crusher.

When small coal is handled, a by-pass valve diverts the flow of coal around the crusher to the hopper below, thus allowing the engine driving the crusher to be shut down. At the bottom of the hopper beneath the crusher is a loading device to automatically deliver the coal to each of the pivoted buckets. The coal is then conveyed to the upper horizontal run, where a traveling tripper discharges it at any point to the storage bunkers.

When it is desired to reclaim the coal from storage to the conveyer, coal is passed through reclaiming chutes, or spouts, located at intervals in the top of the concrete tunnel, to automatic loaders, and thence to the lower horizontal run of the first pivoted bucket conveyer. When this conveyer is not storing, it discharges into a chute placed at the end of the upper horizontal run, this chute delivering through an automatic loader to the second pivoted bucket conveyer.

This second conveyer, 101 feet between centers, is driven through a chain and mitre gears from an upper corner shaft of the first conveyer. A remarkable feature of this carrier is the sharp elevation of six feet in one thirty degree incline, which demonstrates to some extent the elasticity and adaptability of this form of conveyer. Its runways are of steel construction and are bracketed to a side wall when outside the retort house, and to the hoppers when inside. By means of fixed trippers this conveyer discharges into either of two steel storage hoppers of 60 tons capacity each, and clam-shell valves operated from the retort house floor, allow the coal to pass to the retort charges.

This system was installed complete by the Jeffrey Mfg. Co., who are thoroughly equipped to design and build coal and ashes handling systems to suit any requirements.

The Official Organ of the Association of Harvard Engineers

NOVEMBER, 1909

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ENGINEERING AND ARCHITECTURE
AT HARVARD UNIVERSITY

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*Frontispiece.* FIG. 5. [STEEL SHEET PILING.]

Type of piling employed to straighten wall when through inequalities of the rock bottom the toe or head is thrown out of the perpendicular.

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VOL. VIII NOVEMBER, 1909 NO. 3

# STEEL SHEET PILING

THOMAS CURTIS CLARKE

Member of the American Society of Civil Engineers

Piling may be divided into two classes: bearing piles, which, like columns, take their load vertically, and sheet piling, which takes its load horizontally by thrust.

The rapid growth in the use of Steel Sheet Piling in the past few years has been remarkable, and is typical of the way in which new conditions are dealt with in this country.

As real estate enhanced in value, the building of "Sky-scrapers" became an economical necessity, and deeper foundations were required. Foundations placed on bearing piles were discarded wherever bed rock could be reached, and various methods for excavating to a lower level came into use. Where quicksand or other unstable material was encountered, the use of caissons, in the same way that they are used for bridge foundations became common, and engineers readily saw that with large cofferdams the work could be done at less cost; but until Steel Sheet Piling was placed on the market there was in this method of construction no substitute for wooden sheathing, which at best is an expensive material, ranging from planks, driven down edge to edge, to the more elaborate "Wakefield" piling, made up of three planks bolted together in such a manner as to form a tongue and groove.

Sheet Piling is used for any work where it is desired either to stop the flow of water or movement of earth, such as cofferdams, dams, curtain walls, retaining walls, core walls, wing walls, lining for shafts, breakwaters, docks and piers, irrigation work, and building foundations.

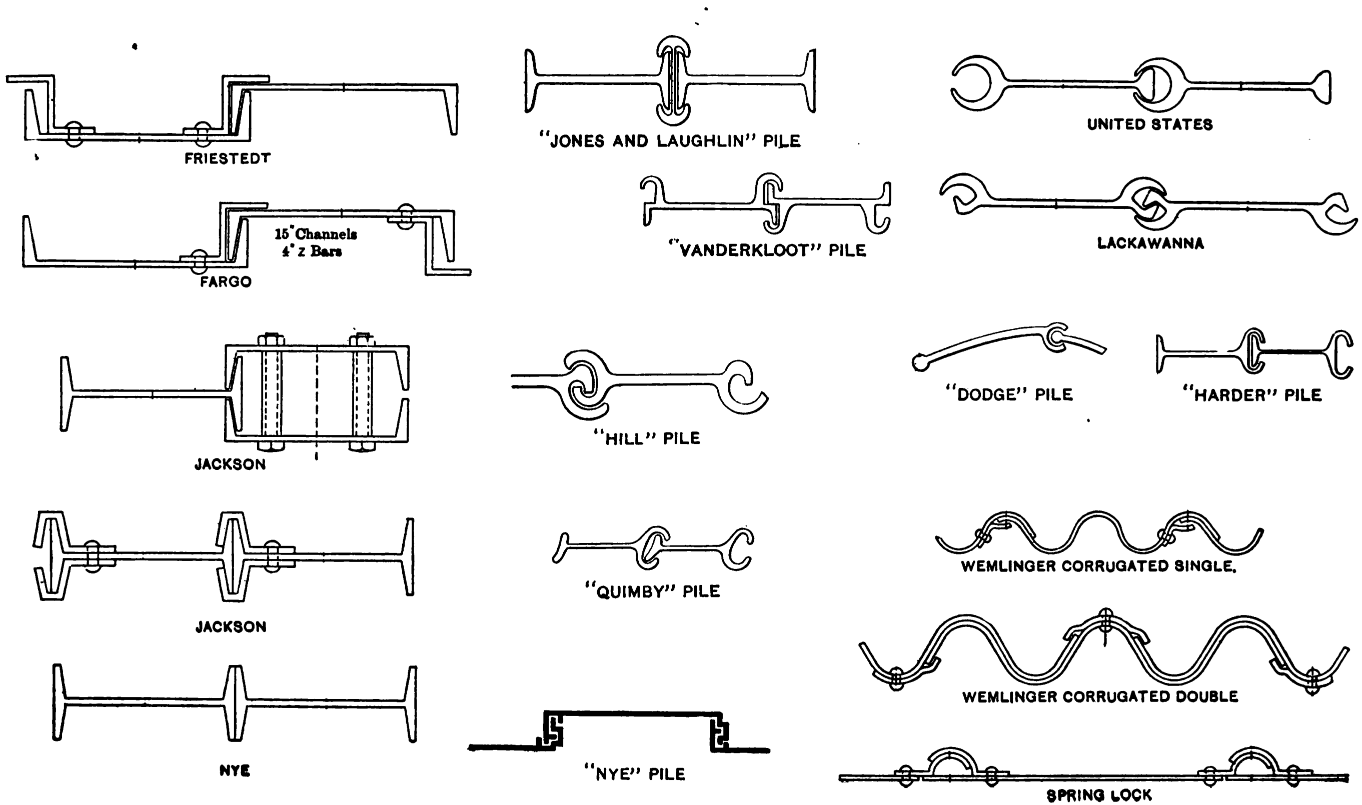

FRIESTEDT
15" Channels
4" Z Bars
FARGO
JACKSON
JACKSON
NYE
"JONES AND LAUGHLIN" PILE
"VANDERKLOOT" PILE
"HILL" PILE
"QUIMBY" PILE
"NYE" PILE
UNITED STATES
LACKAWANNA
"DODGE" PILE
"HARDER" PILE
WEMLINGER CORRUGATED SINGLE.
WEMLINGER CORRUGATED DOUBLE
SPRING LOCK

Fig. 1.

Steel Sheet Piling has come into general use for three reasons: economy of strength, economy of space, indestructibility. To-day progressive contractors consider a tonnage of Steel Sheet Piling as much a part of their plant as they do hoisting engines, cranes, etc.

In Fig. 1 are shown the principle forms of Steel Sheet Piling, and attention is called to a very important difference in design which at once separates the various forms into two types: the "Rigid Joint" and the "Flexible Joint." There are to-day on the market but two "Flexible Joint" steel sheet piles, viz.: the United States and the Lackawanna, both of which consist of one plain rolled section. A comparison of these two rolled types of piling shows that the United States has a two point contact or single lock, whereas the Lackawanna has a three point contact or double lock, giving greater tensile strength and rendering the interlock more naturally water-tight. In the United States the pull is directly against the tips of the two "fingers," which form the socket, giving it a tendency to open up or spread; in the Lackawanna the pull is as in a car coupler, a direct pull of metal to metal transmitted straight through the piling, with the "fingers" acting as guards to reinforce and prevent slipping, and resulting in a much greater tensile strength for the interlock or joint, which is the point where great strength is needed. The Lackawanna Pile is an improvement on the other double lock types, having been designed to permit of its being rolled commercially.

Both types of Steel Sheet Piling, the "Rigid Joint" and the "Flexible Joint," have their advocates. The best claim made for the "Rigid Joint" is that it has a metal to metal resistance against thrusts at close angle, and therefore requires less bracing. There is some merit in this claim; but should failure of the bracing occur through accident or faulty construction, the lower strength of the joints of this type, when in tension, is more apt to result in complete failure of the piling than in the stronger "Flexible Joint" types.

Practically all types of fabricated Steel Sheet Piling are largely made up of standard shapes riveted or bolted together; and an advantage is claimed for them on the theory that when the piling is no longer useful as such, the rivets or bolts can

FIG. 2.

Black Rock Harbor—Turning the corner to close East end of cofferdam. This photograph shows the pockets being filled with material dredged from the bottom.

Fig. 3.

Black Rock Harbor — Pumping nearly completed.

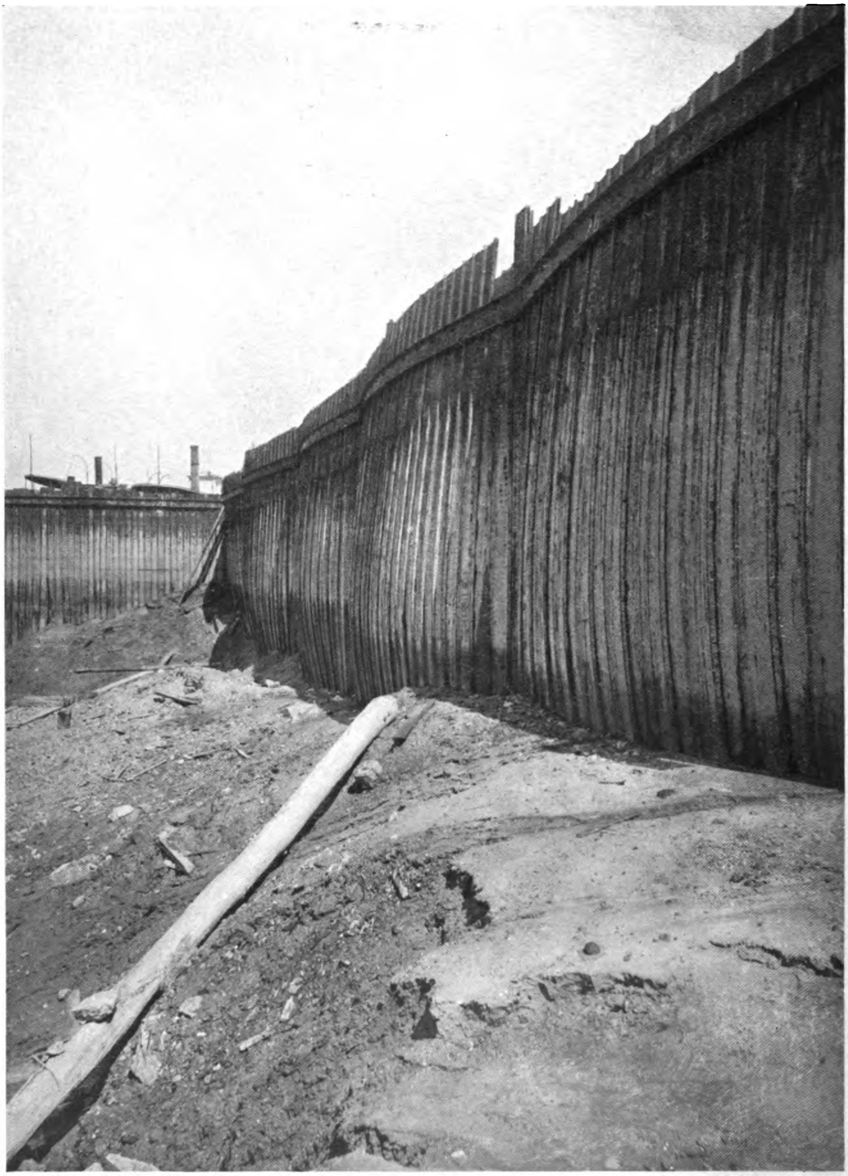


Fig. 4.

Black Rock Harbor — Inner wall of cofferdam, showing resistance to the strain on the piling. This piling has a penetration of 39 feet to bed-rock.

be cut out and the shapes used as second-hand building material. This sounds attractive, but as a matter of fact, in driving, the piling is apt to become bent or distorted; and after it has been in the earth or water, for any length of time, is liable to be too much rusted to come under the head of second-hand building material, and can then only be sold as scrap.

Another argument for these types is, that in case any parts are damaged, in shipping or driving, a piece can be bought locally, and the piling repaired on the spot. The answer to this is that the rolled type does not become damaged in shipping or driving, and has no rivets or bolts to shear off or loosen.

A very important point that the contractor must take into consideration, inasmuch as it represents dollars and cents to him, is the fact that the area of metal to metal in contact, when driving in the fabricated types of piling, is very much greater than in the rolled types, creating additional friction, with consequent harder driving.

The ability to turn an angle with the "Flexible Joint" type of piling is, in the judgment of the writer, the very thing that makes the "Flexible Joint" so greatly superior to the other type.

To any one who has had experience with pile-driving, it is impossible to imagine ground where, for any distance, piling can be driven even ten feet below the surface without encountering obstructions in the shape of roots, stumps, boulders, or something of the kind. Such a condition may exist, but the engineer or contractor hardly hopes to find it. Even where elaborate borings are made, there is little real knowledge of what will be encountered under the surface, except in a broad general way. With the "Flexible Joint" type of piling a line can be laid out and followed until an obstruction is met, through which the piling cannot be driven; one piece of piling can then be withdrawn and redriven at an angle of up to 22 degrees, allowing the piling to go around the obstruction. With the "Rigid Joint" type of piling this is impossible, as the play in the joint does not permit of going out of the straight line, except by a reverse curve of large radius, or

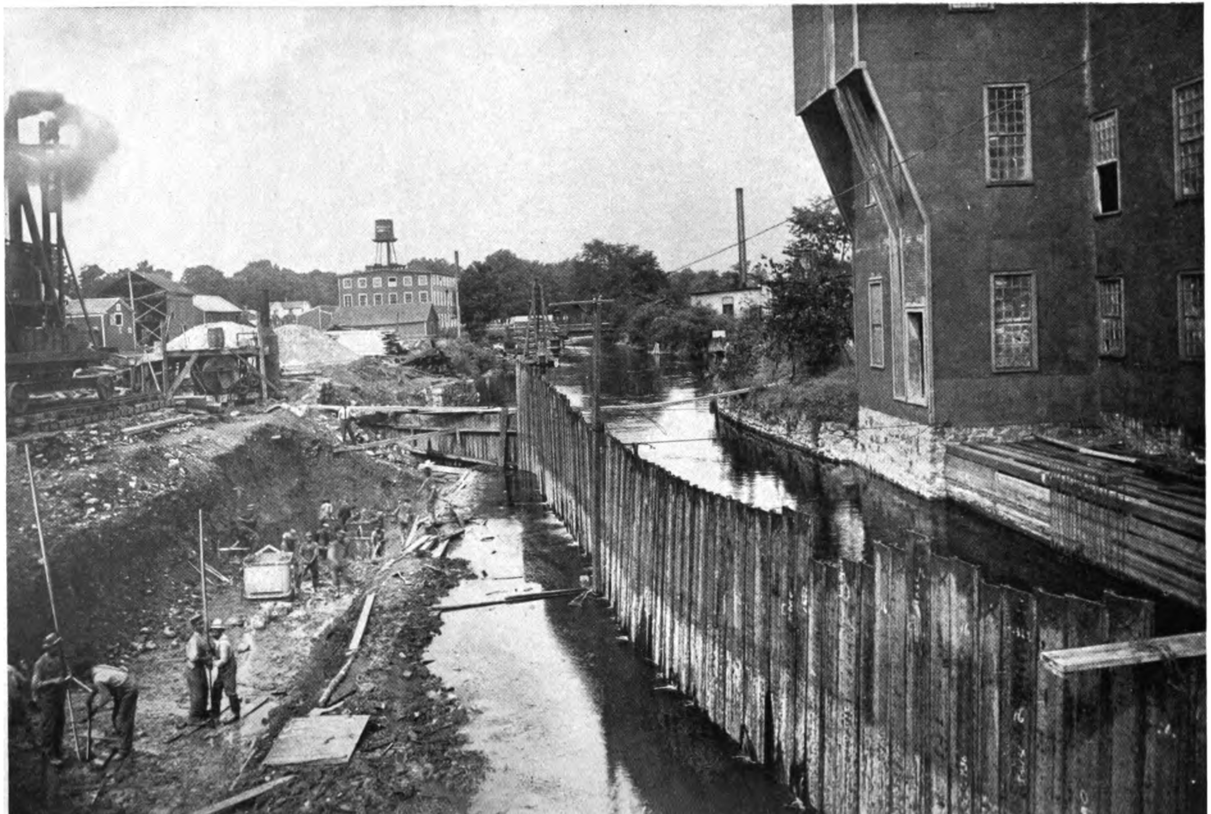


Fig. 6.

Scott Bros. Barge Canal, Baldwinsville, N. Y. — Shows men excavating 4 feet 6 inches under the normal bed of the river, while 6 feet 4 inches of clear water is flowing on the other side of the piling.

fabricating a special corner or 45 degree piece. Should the obstruction be small, it may even force the "Flexible Joint" piling under continued blows to turn to one side, and the piling will go safely by; the next piece of course presenting greater friction in driving, but interlocking safely throughout its length. On the other hand, when the "Rigid Joint" type meets an obstruction of this sort, it has no opportunity to turn out; and continued blows will result in the lock being strained or broken, thereby rendering useless what should be an unbroken wall, and causing, in the case of quicksand or water, leaks in the piling, which may utterly destroy its integral strength and water-tightness.

In permanent installations the cost of Steel Sheet Piling as against wood would, at the present time, preclude its use, and steel is only used in permanant work where water-tightness or strength is essential; but where sheathing is to be redriven steel at once shows economy. To illustrate, wooden sheathing in this district is generally accepted as costing 13 cents a square foot in place — made up of 5 cents for material, and 8 cents for driving. Steel Sheet Piling is being driven in St. Louis, on sewer work, for 2 cents per foot of penetration, the same pieces being redriven twenty times, while wood can only be driven once or twice at most. This gives the following comparison, assuming twenty installations:

| | Wood per sq. ft. | Steel per sq. ft. |
|---|---|---|
| First cost of material................ | $.05 | $.40 |
| Renewal, assuming wood can be driven twice over (9x5 cents)............. | .45 | .. |
| Cost of driving twenty times @ $.08.. | 1.60@ $.02 | .40 |
| Total .......................... | $2.10 | $.80 |

Steel Sheet Piling has been redriven thirty-five times before the top had to be cut off owing to its being battered, leaving the piling as good as new, but shorter than when bought.

As regards corrosion, Professor H. M. Howe in his interesting report of his studies at Sandy Hook, made before the International Congress for testing materials, in July, 1900,

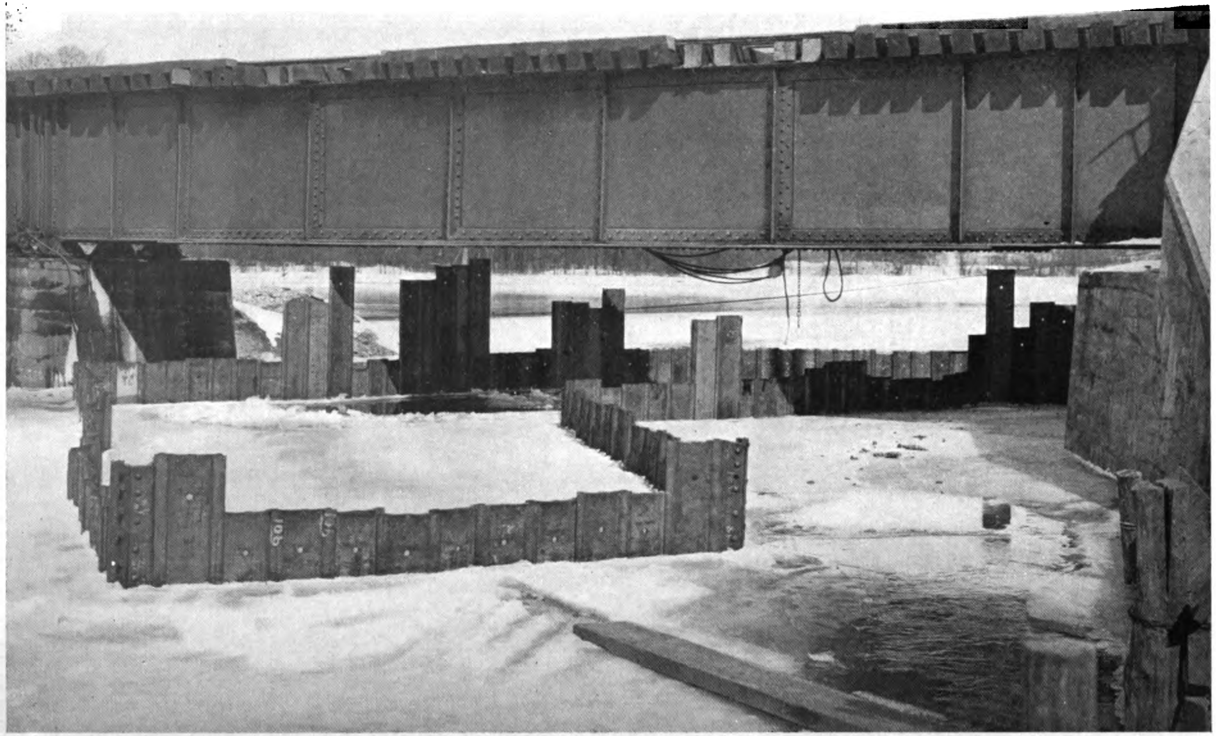


FIG. 7.

**Delaware, Lackawanna & Western Railroad. View showing where the piling had to be driven in two pieces due to the present bridge being in the way.**

Fig. 8.

The small leaks intercepting sewer at Syracuse were due to the necessity of driving the piling in two sections, owing to lack of head room under the bridge.

Fig. 9.

Benjamin F. Smith & Co., New Bedford, Mass. The 7-inch piling being used in trench work for the foundation walls of a large mill. Twelve squares were purchased for this work for the excavation for piers, with the expectation of driving them twenty-one times in this one job.

gives us data that shows the life of Steel Piling, as made in the rolled section, to be sufficiently long to put the fear of failure out of the minds of this generation and the next. Using Professor Howe's figures, but adding 30 per cent to his coefficient, on account of the piling being made of a higher carbon steel than that tested by Professor Howe, which increases the rate of corrosion, we find that in air or clear water in fifty years Lackawanna Piling would lose but 4.8 per cent of its weight. Steel Sheet Piling has further advantages where the use is for a dam where rodents could gnaw through, or in water where teredo, that bugbear of all piling, is present. The 4.8 per cent loss in fifty years through rust is negligible.

The hardest test of driving that has come to the writer's attention was made early this year at Cleveland, Ohio, for the Engineer of the Lake Shore & Michigan Southern Railway, Mr. H. M. North. Mr. North had used Steel Sheet Piling and had had the jaws of the interlock opened by gravel being forced in and was skeptical of the results under severe conditions. The Lackawanna Steel Company offered to drive five test pieces 50 feet long, and pull them out again to show what happened. Borings showed conditions to be:

Furnace slag and cinders........ 0 ft. to 5 ft. below surface
Yellow clay and gravel......... 5 ft. to 20 ft. below surface
Fine gravel....................20 ft. to 30 ft. below surface
Coarse gravel..................30 ft. to 40 ft. below surface
Fine sand.....................40 ft. to 50 ft. below surface
Coarse sand...................50 ft. to 55 ft. below surface
Blue clay (said to be shale rock)..55 ft. down

The driving record was as follows:

| Pile | Highest number of blows per inch of penetration | Penetration | Total blows | Time taken to drive |
|---|---|---|---|---|
| 1 | 90 | 49 ft. 8¾ in. | 2026 | 34-½ min. |
| 2 | 41 | 49 ft. 5¾ in. | 1148 | 20 min. |
| 3 | 30½ | 48 ft. 2 in. | 1572 | 23 1-6 |
| 4 | 52 | 49 ft. 0 in. | 2284 | 35-¼ min. |
| 5 | 19 | 49 ft. 1 in. | 1283 | 20-¼ min. |


Model cofferdam with miniature derrick inside, standing on dry sand, with the water outside the piling, showing the interlock to be watertight.

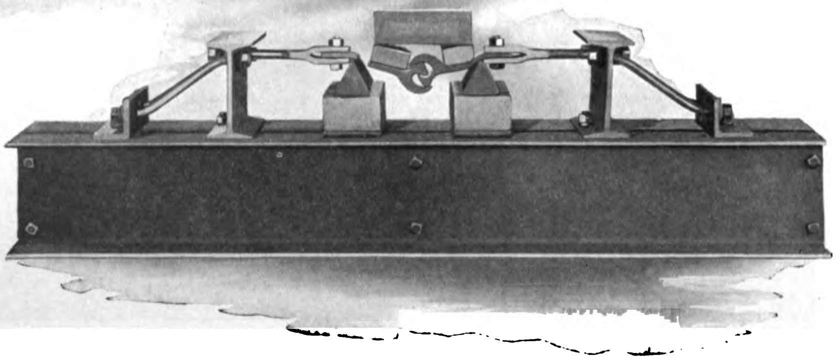


**Fig. 10.**

**Lackawanna piling tested to destruction. The web sheared at 45,000 pounds, leaving the piling still interlocked.**

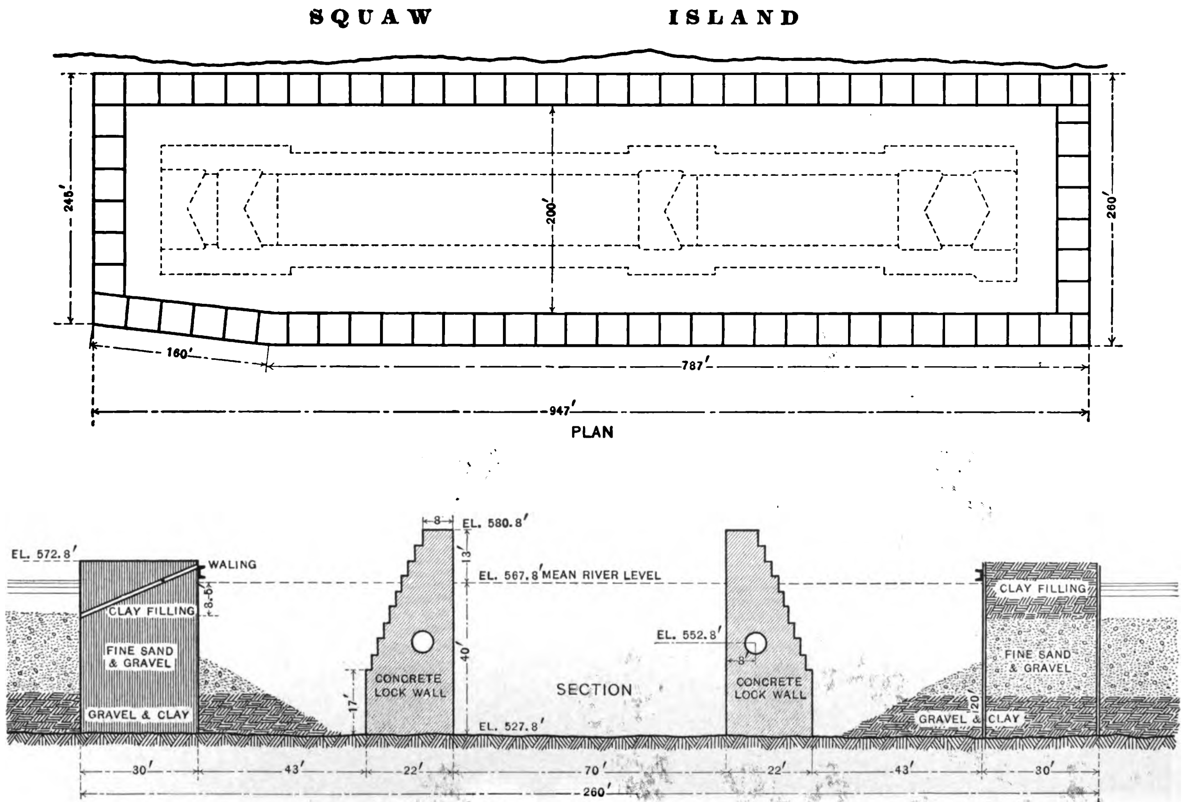



FIG. 11.

Cofferdam for the New Government Ship Lock in Black Rock Harbor, Niagara River, Buffalo, N. Y.

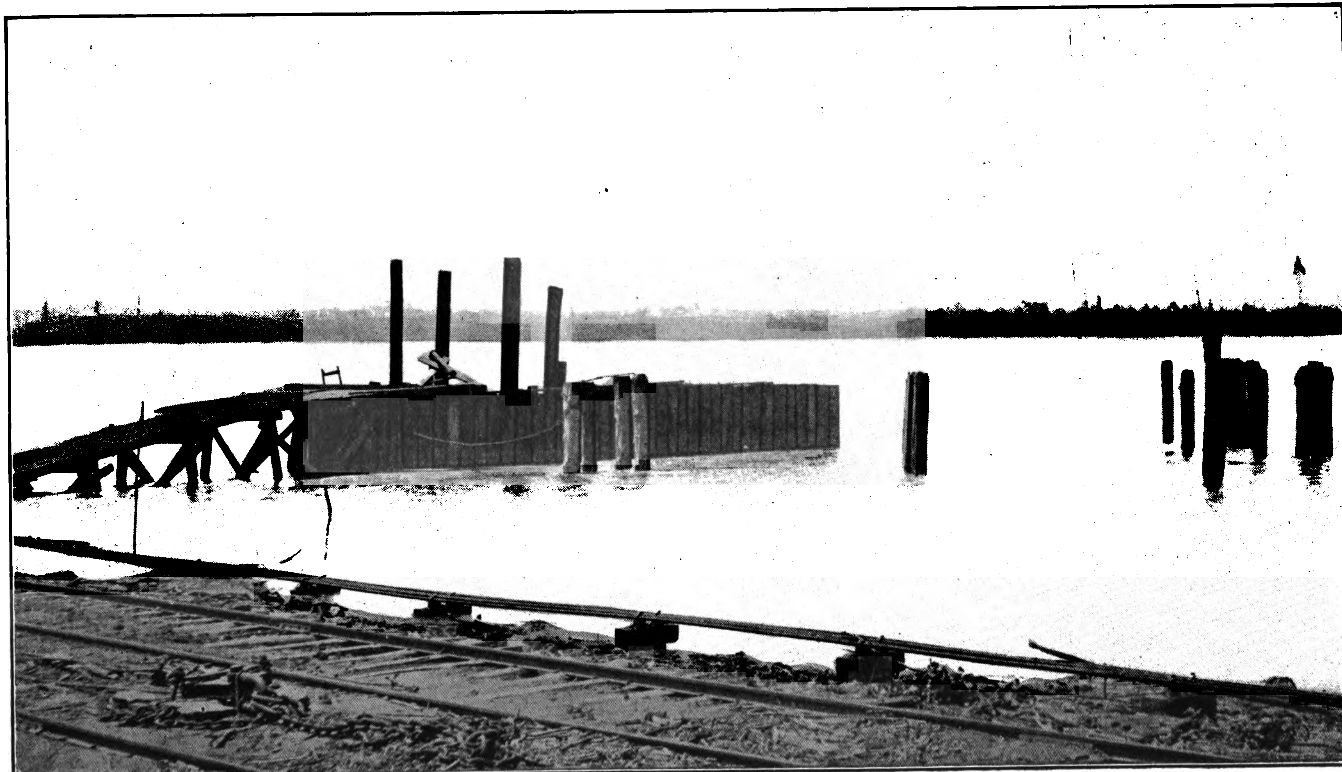


FIG. 12.

The record of this test aptly illustrates the remarks on the subject of not knowing what may be found under the surface, even when borings are obtainable. The very hard driving shown by ninety blows of a five-ton hammer to obtain 1 inch of penetration, all occurred between 44 feet and 49 feet, where, according to the boring, "Fine Sand" was to be encountered. The writer has no doubt that the fine sand was quicksand under compression, which always makes hard driving, but it will be seen that in five pieces of piling driven under the same conditions there is a variation of from 1,148 blows to 2,284 blows to give practically the same penetration. These five pieces of piling were subsequently pulled and are now on exhibition, the first time, as far as the writer knows, where Steel Sheet Piling 50 feet long has ever been pulled.

Another remarkable instance of difficult driving is reported by Mr. George C. Holmes of St. Louis, Mo., who writes as follows: "In order to explain to you we will say the cofferdam is a parallelogram driven east and west in the river. It now develops that near the eastern end and a few feet inside of the wall they encountered a sunken and abandoned trestle railway that at one time evidently was used in loading cars on ferries. Strange as it may seem, one of the piles in the north wall of the cofferdam drove completely through the west rail of the track (which ran north and south), then through a tie, and to cap the climax through a 10x12 foot yellow pine stringer. This sounds remarkable, but is a fact, and the piling was driven its full length, the same as the others. The three that did not drive all the way down were found to be resting on other parts of this same track. One pile in the south wall, which struck the same west rail practically got through too, but evidently they found it such hard driving that they gave up just as they were getting through. On examination, the web of the piling was found to be torn for 3 inches, but otherwise undamaged. The rail is a No. 60 section, and if this record can be beaten, I would like to know it. Steel Piling made friends for itself on that work, certainly."

Some of the illustrations shown are of Black Rock Harbor, in the United States Government improvement of the Niagara River at Buffalo, N. Y., said to be the largest steel cofferdam

ever constructed. The Lackawanna Piling, which was used in this work, was selected by the contractors, with the approval of the United States Engineers, after tests had been made of it and various other types. A series of pockets, 30 feet square, were driven and then filled with clay, making a water-tight wall, at much less cost than could have been done in any other way. This huge pocket is being excavated down to bedrock, and the walls of the lock will be laid in the dry, where every yard of concrete can be inspected. The best pile-driving record made on this work was with a No. 3 Vulcan Steam Hammer, which hits a short, sharp blow, which has been found to be better practice in pile-driving than the slower blow, with long drop, given by the drop-hammer. Sixty-six piles were driven in eight hours, with a penetration of 31 feet to bedrock, each pile being 50 feet long.

Other illustrations show various typical uses of "Flexible Joint" Steel Sheet Piling.

The subject of Standard Specification has been gone into by our engineering societies, but as yet, the only point agreed upon is that the "Standard Specification for Building Materials" shall govern the physical and chemical tests of the metal in the piling. For more complete data on this and other points in connection with Steel Sheet Piling, the reader is referred to the paper by Mr. L. R. Gifford, associate member of American Society of Civil Engineers, and the discussion of same as published in Vol. LXIV, page 441, (1909) of the Transactions of the American Society of Civil Engineers.

It has been the writer's aim in this brief article to call attention to a new engineering material, the development of which is so recent that it is not generally known outside of a limited number of engineers and contractors; but which is of such great economic importance that it should be more fully studied, and definite and accurate data in regard to its use placed within reach of all.

# THE VALLEY CITY VIADUCT

C. R. MANDIGO

The railways which first pushed through the unsettled West were not located with a view of handling such an enormous amount of traffic as they are now called on to do. Consequently the past ten or twelve years have seen many millions of dollars expended in reducing grades and curves, to say nothing of double tracking and increasing terminal facilities. Expenditures that are now not only advisable but necessary would have been foolish and impossible when the roads were first constructed. Such a case occurred at Valley City, North Dakota, on the Northern Pacific Railway. In crossing the plains

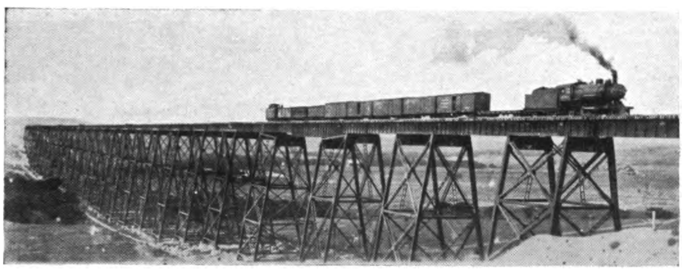


FIG. 1.

View from east end of completed bridge. Third car from caboose is over one 101-foot span.

of eastern North Dakota, the railway had encountered the deep, wide valley of the innocent-looking Shyenne River, and twisted down one side and up the other with a maximum grade of 2.6 per cent and a maximum curvature of 8 degrees. Since this was much greater than any other grade on the Fargo-Jamestown Division, pusher engines had to be maintained there for all freights and heavy passengers; making it more and more difficult and expensive of operation as the amount of traffic grew. In order to eliminate this extra expense, a cut-off at a narrow point in the valley, about $\frac{3}{4}$ of a mile from the main line, was decided on. At first it was thought possible to cross on a dirt embankment with bridges over the M., St. P., & S.

St. M. Railway and the river. As the valley is nearly a mile wide and 200 feet deep at this point, such a plan was very costly, and investigation made it doubtful whether or not the top soil would support such a load, — a conclusion which subsequent events proved. It was finally decided to use embankment as far as practicable, and to cross the valley by a steel viaduct capable of carrying two tracks.

The cut-off leaves the old main line on the east and, by cuts and fills netting 500,000 cubic yards in four miles, joins the viaduct by a 50-foot embankment projecting into the valley some 300 feet. It leaves the valley on the west by a 60-foot fill 600 feet long, and joins the main line 5 miles further by cuts and fills, netting 800,000 cubic yards. The total length of the cut-off is about ten miles; the reduction in distance is 0.66 of a mile; the maximum grade is 0.2 per cent; curvature, 2 degrees.

The steel viaduct is 3,753 feet long and 147 feet high at the river. The design of the steel work is similar to other railway viaducts. It consists of a series of 30 steel towers, each tower resting on four concrete piers and supporting a set of two girders for each track. The girders across the top of each tower are 45 feet long; and the span between towers, with three exceptions, is 75 feet. Two spans over the river and one over the M., St. P., & S. St. M. Railway are each 101 feet. Timber abutments were built at the ends of the viaduct, to be replaced by concrete later. At present only the set of girders on the north side has been placed; the other set can be easily put in when a double track becomes necessary. There were only three different girder-spans to be designed and about twelve different towers, — the design repeating itself for the rest. An objectionable feature is a 2-degree curve running from the west fill 200 feet out on the bridge, but owing to the lay of the land there seemed to be no way of eliminating this without greatly increasing the cost.

The foundations were designed from the results of a careful set of borings made along the line of the viaduct. On account of the high level of the ground-water in the bottom of the valley and the depth of silt, piling, sheathing, and pumping were necessary in a majority of the piers. There

were four coffer-dams of Wakefield sheathing in the river. A 4-inch centrifugal pump was used to pump each dry at the start, after which a pulsometer steam pump was usually able to keep out the leakage against a 17-foot head of water. A blow occurred in one coffer-dam, which was stopped by a mixture of clay and straw dumped along the outside. The piling in the river was driven before the coffer-dams, which made excavation difficult.

### Piling

The piling used was all Douglas Fir, not less than 8 inches at the small end and not less than 10 inches nor more than 14 inches at the large end, all bark removed. The 16 to 36 piles in a pier were spaced 3 feet center to center, and cut off 1 foot above the bottom of excavation. In a few piers on the side hill, piles were driven in dry ground. At first thought this may appear unnecessary, since the piles will rot in course of time. It was done, however, as a precautionary measure to compact the bearing soil, to prevent any settlement, and especially any tendency to slip down hill. The tendency of the top soil to slip was shown in the case of the embankment on the east end. The soil underneath this fill commenced to slip down hill as the load increased, and let the top of the fill down as much as 10 feet in one night. The ground at the foot was broken up in big rolls for 100 feet, making necessary a temporary substitution of pile piers for the concrete in the east tower. A penetration of 1.5 inches in the last ten blows of a 1,200-pound hammer falling 15 feet was required for each bearing pile. This makes each pile capable of supporting a load of 7.2 tons by the *Engineering News* Formula. A great many piles, however, were driven to refusal. About 78,000 linear feet of piling were driven.

### Concrete

The cement for concrete was furnished by the railway company: the contractor unloaded, stored, and used it in mixing concrete. This proved a very good arrangement, as the amount of cement could be varied to suit the aggregate without any argument with the contractor. Each car was sampled; boiling tests made on the works, and fineness and tensile strength tests in St. Paul.

The sand was obtained from a bank close at hand, and proved uniformly clean, coarse, and sharp. Crushed rock was shipped from the blue limestone quarries around Minneapolis. At first it was thought possible to use gravel from near the work and a screening plant was installed; but this gravel contained clay which would not screen out when damp, and each piece was encrusted with sand, so that the plant was abandoned after a time. The material was switched in on a track laid just outside the line of piers, and platforms were built from this track to the mixers. This arrangement allowed the material to be wheeled directly from the cars to the mixer.

All piers have the same sized top: a coping course 6 feet 6 inches square and 18 inches thick, with an offset of 3 inches from the battered course below. The battered portion extends down to the ground level, thus varying in height with the height of the pier above ground. Below this are from one to three square offset courses. The bottom course is from 15 to 20 feet square, 5 feet thick over piling and 4 feet thick in piers where there is no piling.

The forms were made of 2x12's, braced with 2x8's, and put together in sections so that they could be easily taken down and reset. Battered forms for high piers were sawed off and used for low piers. The forms above ground were tied together by twisted telegraph wire, besides being braced from the ground to prevent lifting or being thrown out of plumb. About 1,500 pounds of wire were used altogether.

The concrete was a 1-3-5 mixture except for the copings, which were 1-2-4. According to specifications one part cement was taken as 376 pounds, or one barrel and one part sand or rock, as 3.5 cubic feet. With rock screened of all particles less than $\frac{3}{8}$ of an inch, three sacks of cement made about 17 cubic feet of concrete in place. When rock or gravel containing dust or sand was used, the amount of sand was reduced and rock increased to give the same sized batch with the greatest amount of aggregate. The average for the whole work, including copings and finishings, was 1.23 barrels of cement for each yard of concrete. Clean hard boulders to the amount of 20 per cent of the volume of concrete were allowed to be thrown in the footing courses, but this was not taken advantage of by the contractor to the extent allowable.

All concrete was machine mixed, there being three mixers on the work. Two methods of transporting concrete from mixer to pier were used: by dump cars pushed by hand along an 18-inch gauge track, and by a cableway carrying a one-yard dump bucket. Track for the cars was laid from the mixers over several piers at a time. These cars were used


FIG. 2.

View of steel work in completed bridge.

only for concrete below ground in the bottom of the valley, because of the expense of constructing track above ground or on a steep slope. The cableway was 1,200 feet long and set up between the lines of piers. The concrete dropped from the bucket into a shute and slid into the form. At first these shutes were torn down and rebuilt at each pier, but two strong,

well-braced shutes were made, and these were moved when necessary by the cableway. On a long haul, either by cableway or dump cars, concrete was placed slowly so that the force at the mixer had to be correspondingly reduced. The cableway was used for all concrete not placed by cars, for transporting forms, lumber, and lifting out the pile cut-offs. It proved very satisfactory after a good engineman was obtained who could understand signals. The force necessary to transport concrete by the cableway consisted of an engineman, signalman, a man to dump the bucket on the shute, and one to place the bucket under the mixer.

All concrete was mixed so wet that the man spreading had to wear rubber boots, and even then was not safe. This made tamping unnecessary, prevented a separation of ingredients in dumping from a height, made the concrete leave the bucket, car, or shute easily, and prevented the formation of rock pockets in the finished work by making spreading easy. Not a rock pocket larger than a cocoanut appeared in the whole work when the forms were removed. The sides of the forms were spaded as a further precaution.

Considerable difficulty was experienced in placing the first course of concrete in piers where there was water. The piers were first pumped dry, the concrete dumped in the center each time and crowded out against the water which leaked in. One corner was left low for the water to collect, when it was pumped out with very little loss of cement. This method presented the same edge of concrete to the water all the time and prevented washing. Dry concrete was tried in order to absorb the water as fast as it came in, but proved difficult to handle and unsatisfactory. In the coffer-dams, which were large enough to allow a form for the bottom course, the pump was placed between the form and the sheathing, and the pit kept dry.

While the concrete of any one course was soft, a number of holes, a foot or so deep, were dug to form a bond for the next course. Then, when the next course was ready to be placed, the old concrete was first swept and the holes cleaned out, all laitance removed, and the surface thoroughly wet; dry cement

was then sprinkled over it, and the fresh concrete deposited on this. The battered portions and copings were put in without a joint.

The forms were removed as soon as the concrete would stand up and while it was yet green, — from twenty-four to forty-eight hours, depending on the weather, — and the exposed surfaces of the pier finished. This was done by daubing a little 1 to 3 mortar on the rough and chipped spots, and then grinding down the surface smooth and even with a wooden float and plenty of water. If the concrete had become too hard, sand was used with the float. Plastering was not allowed and what little mortar was used, was thoroughly incorporated with the concrete. The whole was then brushed over with a thin cement grout. This method gave an exceptionally neat and uniform appearance to the piers, and removed all marks of the forms. No hollow spots appeared, even when the finishing was done in hot weather. Greasing the forms with oil and soft soap was tried, and, although this prevented the concrete from sticking, about the same amount of finishing had to be done in any case.

The last 600 cubic yards of concrete was placed in freezing weather, sometimes with the temperature around zero. The water for the concrete was heated and a steam jet was turned into the mixer, but no attempt was made to heat the sand or rock. A wind-shield, with no top, was built around each pier, and salamanders of burning coke placed between it and the pier. The concrete was also well protected by manure. The salamanders were the contractor's idea, but did little or no good, out in the open air as they were, except to keep the workmen warm. The concrete was so thick and so well protected by forms and manure, that there was little danger of the frost penetrating to any depth as long as the concrete did not freeze before it was in place. This section of the work turned out every bit as well as that put in during the summer. The total amount of concrete, placed in the one hundred and sixteen piers built at that time, was approximately 9,500 cubic yards.

### Steel Erection

The erection of the steel work started when about half the concrete was in place. The cast iron pedestals for the steel

columns were first placed in position on the piers. To secure them 24-inch expansion bolts were grouted into holes drilled in the concrete. This proved a slow difficult job, but setting these bolts by template in the fresh concrete was not deemed advisable because of the high degree of accuracy required in their position. At first the steel erection was done by two railway track derricks which worked from the track above as fast as it was laid out on the girders. One derrick, with an 80-foot wooden boom, was used in erecting the bents of the towers; the other, with a 45-foot boom, was used in handling the heavy girders. When lowering a column, before erection was very far advanced, the 80-foot boom broke. Although this was partly the fault of the derrick engineman, who let the doom down nearly horizontally, this method of erection was seen to be slow and impracticable. Another and more successful method was then devised. Two railroad tracks were laid between the line of piers and carried over the river and low spots on temporary pile bridges. Two freight car trucks were placed on each track, and a wooden tower, 90 feet high, was built on these. A derrick was placed on top and the derrick engine near the ground in the middle. The steel erection was then carried on from this frame tower, except that the girders were placed by the track derrick above as before. Forty per cent of the rivet-holes were bolted by the erection gang, the riveting gang following close behind. The total amount of steel in the viaduct at present (with one set of girders) is a little over 7,500 tons.

The cut-off has been completed and in operation for over a year now, at a great saving to the railroad company. The total cost of this ten miles of new construction was in round numbers $1,000,000. The question then is, does the saving in expense of operation of the new line over the old counterbalance the interest on capital outlay, increased taxes, depreciation, and maintenance? If it does not or will not in the near future, then the railroad company is losing money in building it and should have sought a cheaper means of reducing grades. At present it scarcely seems probable that there is a saving, but if the rapid increase of traffic of the past ten years continues, the viaduct will soon be a paying investment.

## BRIDGE DESIGN FROM THE ARCHITECT'S STANDPOINT

BY CHARLES W. KILLAM

A bridge is so prominent a feature in the landscape, that attention should be given to its appearance as well as to its economical design. Of course the importance of its appearance may vary greatly with its surroundings, some cases demanding only that the engineering design shall not be an ugly one in itself; while others, as in bridges in parks, in cities or near important buildings, require and rightly require that the greatest care be given to their design, and that additional money be expended if necessary to make them handsome. A public building is never intentionally built as a bare ugly structure, some attempt is always made to beautify and adorn it. Why should not a bridge, which is usually even more conspicuous, be given equal care? European bridges, built in the past, have been much handsomer than those in this country; and the German concrete bridges of to-day are many of them very interesting and suggestive in their adornment — an adornment which seems to take its motive from the structure of the bridge itself, rather than from any traditional architectural manner.

The engineer and the architect are both interested in this subject, the former because he alone may make or mar the design, the architect because he is more and more being called in to collaborate with the engineer in the design of large bridges or in small bridges where harmony with surroundings demands consideration.

Modern materials and methods, in the building of bridges, make it worth while to consider some of the examples which are satisfying in appearance and to discover, if possible, the elements of their success.

In environments where appearances count at all, a type of structural scheme should be chosen which is good looking. Few people really admire the cantilever truss bridge, for instance, especially when made up of a number of unequal spans. The Blackwell's Island Bridge, in New York, is undoubtedly the

least satisfactory bridge across the river in appearance, not to be compared with the steel arched Washington Bridge over the Harlem, or the suspension bridges over the East River. Another fundamental element of success is that the bridge should not only be strong, but should look strong; and this appearance of abundant strength may be obtained by liberality in the engineering design, so as to make the members look ample rather than simply adequate. Symmetry is always a valuable characteristic. Spans increasing from the abutments toward a wide middle span always give a more satisfactory appearance than an arrangement with a wide span off the centre. Symmetry of materials and design about the middle is always better than to have, for instance, steel spans on one end of a bridge and masonry arches on the other end. Then the structural scheme of the bridge ought to be evident at a glance, and any adornment should accentuate this structural scheme rather than confuse it. This is of course a truism but is, nevertheless, often disregarded. Of course the structural schemes of some of the complicated steel trusses are less easily grasped by the layman than the simpler plate girder or the voussoir arch.

It may be worth while to consider some of the types in detail to discover if possible the characteristics which generally please.

The steel plate girder is much in use for the shorter spans, and has been used in lengths up to one hundred and thirty feet and in depths up to ten feet. Made up of a solid vertical web plate, with double angles at top and bottom edges, and with varying numbers of flange plates it is a simple, easily understood form. Its very simplicity makes it harmonize better with most surroundings than steel trusses which are more complicated and usually rise higher above the floor. Plate girders are commonly made with top and bottom flanges parallel and level. Sometimes the top flange is built in a convex curve, and sometimes both top and bottom flanges are cambered, as where a highway with inclined approaches crosses a river or railroad; the camber of the girder then continuing the slope of the approaches in a graceful way as at the Harvard Street Bridge over the Midland Division in Dorchester.

An architect who thinks a curve is the only line of beauty may try to arch the lower flange of a girder leaving the upper flange level as on the Harvard Bridge between Boston and Cambridge; but this violates the laws of strength in beams, that the strength increases greatly with the depth and that the greatest strength and therefore the greatest depth is required at the middle. It is true that it is possible to make up for the lesser depth by adding more flange plates, but this additional strengthening element is not easily apparent; and the form does not satisfy the engineer or architect who understands the principles of the strength of beams. The curve suggests an

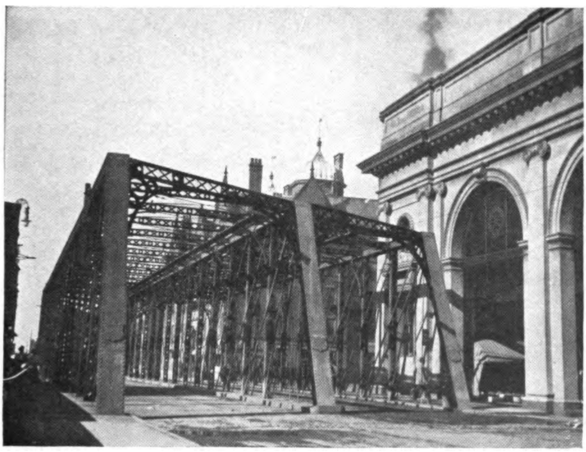


FIG. 1.

arch when there is really no arch action and that is confusing. It will be generally conceded that for spans up to a hundred feet or so a plate girder is a much pleasanter form to use than the ordinary truss with parallel chords. For instance, the strictly utilitarian plate girders carrying Massachusetts Avenue over the Fitchburg Division, in Cambridge, are much less offensive than the through trusses carrying Dartmouth Street over the railroad tracks at the Back Bay Station (Fig. 1). The latter are high, rising into a prominence which they are not beautiful enough to deserve, and they blanket the station awkwardly. A similar bridge disfigures Newton, near Nonautum Square. If a structure in an important city street cannot be beautiful,

it should at least be unobtrusive. The trusses carrying Blue Hill Avenue over the Midland Division, at Mattapan, are another example of unbeautiful utilitarian form in a prominent position. Plate girders would have been much less aggressive, and the passing of a great boulevard over a railroad near a station ought to demand a better looking bridge, even if some additional expense were involved.

Where the span increases to more than, say, one hundred and twenty-five feet and a steel truss is required, the type with horizontal bottom chord and convex or polygonal top chord,

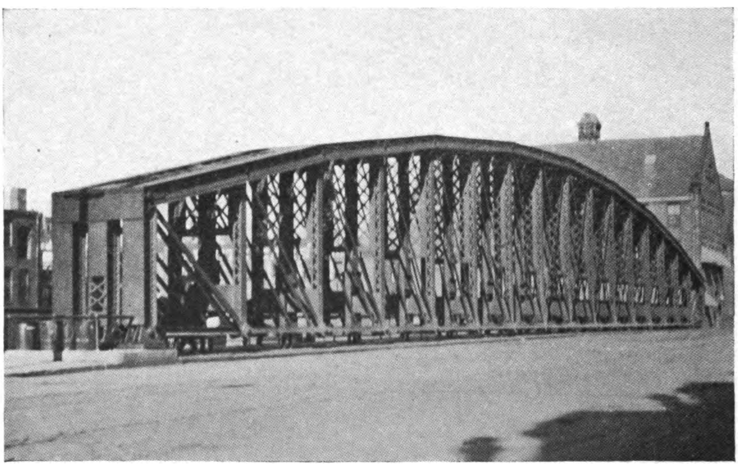


FIG. 2.

like those carrying Boylston Street over the Albany Railroad in Boston (Fig. 2), seems to satisfy the eye better than any of the types with parallel top and bottom chords; partly, perhaps, because the greater height in the middle makes it look stronger, and partly because the curved line in itself is more interesting than a straight one. Much of the structure of the Paris elevated railway is built of trusses with convex top chords. If the ordinary truss with parallel chords and inclined end posts (Fig. 1) must be used, it is probably best to make no attempt to adorn the outline with pinnacles at top of end posts and other applied ornaments as has been attempted in Germany. If the joints are rivetted the gusset plates may be cut with re-

entrant curves as is done in the structure of the Boston Elevated Railway, giving a pleasanter outline than the usual polygonal gusset plates and fulfilling the structural office just as well.

One difficulty with any truss is that the function of each member is not always clear from its cross section; that is, the layman cannot tell which are in tension and which are in compression. A part of the enjoyment of any structure consists in a clear appreciation of the functions of its parts. The engineer can see from his training and by noting the use of eye bars or latticing, what the different members are doing, but the layman sees only a maze of steel bars without the simple definite structural clearness of a wooden or steel beam or of a voussoir arch.

For the longest spans either the cantilever, the steel arch, or the suspension bridge may be used. The greatest stresses in a

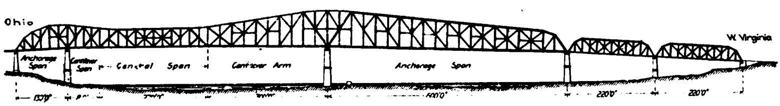



FIG. 3.

[Reproduced by courtesy of Engineering News, New York.]

cantilever bridge are at the fulcrum supports; and the trusses are usually made deepest at these points, either by designing the top chord to rise by concave curves to a point over the fulcrum as on the Blackwell's Island Bridge in New York, or curving both top and bottom chords to points as on the Firth of Forth Bridge. Where a cantilever bridge can be symmetrical about a center line either of these arrangements may be satisfactory, but where cantilevers must be combined in the same bridge with a number of simple trusses with unequal spans the problem is more difficult. If the outline of the various top chords is fixed only by the requirements of the individual spans, as on the bridge over the Ohio River at Marietta, Ohio (Fig. 3), the irregular line of the top chords is very unsatisfactory. In such cases it would seem worth while to keep the top chords of all the simple truss spans at one level, even if the cantilever span must be higher.

The steel arched bridges differ from the girder, simple truss, and cantilever bridges in that they have the familiar arched form and that there is a lateral thrust at the supports. The arched form is most often used where a way must be carried across a deep ravine or valley where the supports may be brought down to the ground without interfering with the clearance underneath, and where a firm foundation may be found to resist the thrust. Such arches may be three hinged, two hinged, or hingeless; the first, with one hinge or pin at the crown

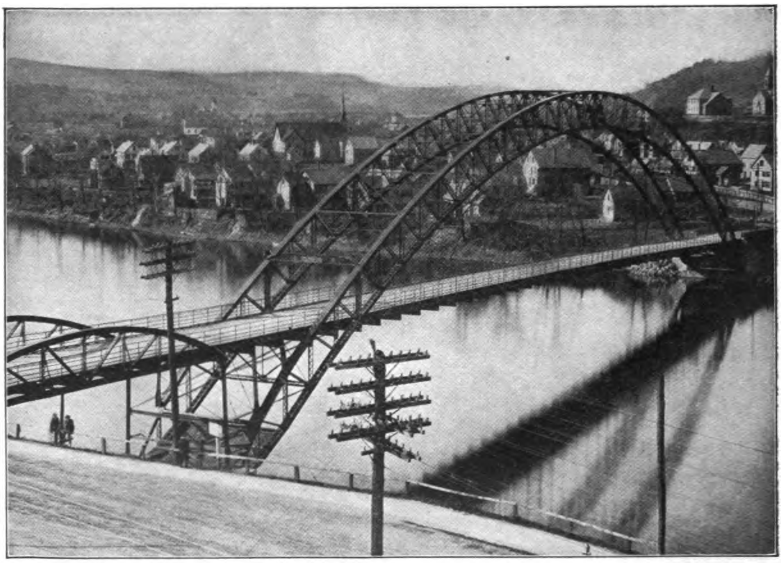


FIG. 4.

[From "Erection of the Bellows Falls Arch Bridge" by Lewis D. Lights. *Trans. Am. Soc. Civ. Engrs., Vol. LXI, page 260.*]

and one at each support, being often used. Then the variety called the braced arch, consisting of a horizontal top chord and a curved lower chord is often used. In either type the crown pin is some times accentuated by bringing the chords of the segments frankly to a point at the hinge, while in other cases the hinge is concealed in various ingenious ways so that the top and bottom chords are continuous. Between the hinges the segments may be plate girders like the West Boston Bridge or trussed like the arched bridges at Niagara Falls or the highway bridge at Bellows Falls (Fig. 4).

On these arched bridges the roadway, usually level, may be carried across above the crown of the arch and supported by vertical columns from the arch or, as at Bellows Falls, the roadway may be supported at a point intermediate between the spring and crown of the arch, depending of course on the local topography in any case. The very beautiful Alexander III Bridge across the Seine, at Paris, is a three hinged arch with cast steel segments and a very low rise. The arched form of bridge seems to commend itself to both engineer and layman as the most beautiful form of steel bridge where it can be used. One reason is that, for most purposes, a curve is intrinsically more beautiful and interesting from various points of view than a straight line. One likes it better in nature in the curved line of a beach or a winding road in the woods or, in art, in the curved wall of a building like the Stadium or a curved street of facades. Then the arched form reminds the layman of the familiar masonry arch; and he feels that he can, by analogy, understand the structure of a steel arch better than the steel cantilever for instance.

The suspension bridge is generally considered even more beautiful than the steel arch perhaps sometimes for its mere size, but also for the graceful curves of cable and roadway and the comparative slenderness of its parts. It is difficult to explain why this slenderness is attractive in a suspension bridge and not in a steel truss. Perhaps here again the reason is that the structure is simple and evident to the layman in its essentials. He is familiar with ropes and knows that a small rope will support a large load, whereas the compression members of a steel truss seem to him too slender compared with the compression members of wood or masonry with which he is more familiar. It is interesting to study the development of the supporting towers in the three suspension bridges across the East River in New York. In the stone towers of the Brooklyn Bridge, the first one built, there is no attempt to suggest that the upper part is simply to support saddles carrying the cables. The saddles, which ought to be a conspicuous part of the design, are buried in masonry, the cables apparently simply perforating the towers. In the Williamsburg Bridge, the next one built, the towers are of steel, and their saddle supporting

function is more clearly marked; but the towers are vertical from the ground to the roadway, and then they suddenly batter inward to the saddles giving a bow legged effect that is decidedly unpleasant. The steel work was designed, however, with a praiseworthy attempt at grace of outline. The towers of the latest bridge, the Manhattan, seem to be much the most successful of the three. They are designed to deflect with temperature and are slender and tapering from a curved en-

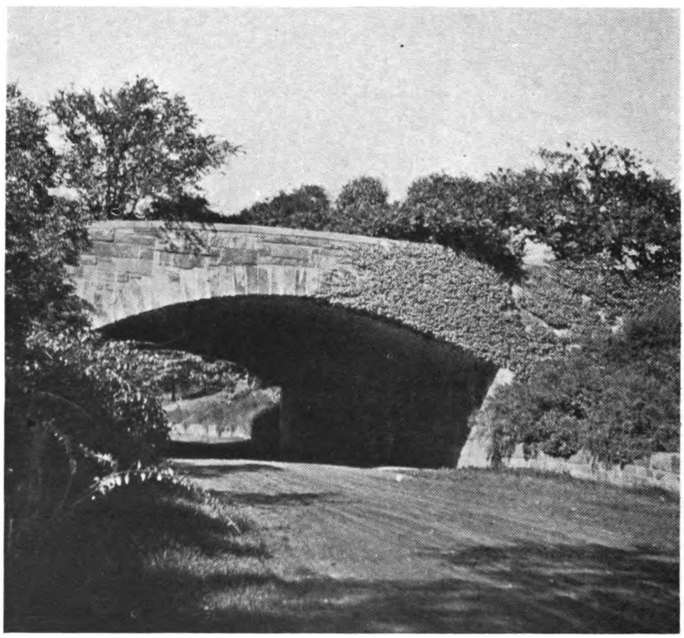


Fig. 5.

largement at the base to a strongly marked and gracefully designed saddle at the top, and with the levels of the roadway marked by projecting curved balconies , which serve as resting places for observation. There is little applied ornament, the beauty arising from the carefully studied outlines of the structural members — the legitimate source of beauty in a bridge. The ill-fated Quebec Bridge was an example of tremendous structural members frivolously " ornamented " by little mouldings, ignorantly applied, and capped by futile pinnacles. The

bridge would have been much better looking without them. A big bridge ought not to be feebly ornamental.

Coming now to the masonry bridges, they have always the advantages of permanence and massive proportions as well as harmony with surroundings. A masonry bridge costs practically nothing for maintenance, which recommends it for railroad and other utilitarian purposes, and its simplicity of form and harmonious materials make it appropriate where it must be surrounded either by park scenery or by masonry buildings. In parks the masonry may be of the same stone as outcropping ledges or park buildings or it may be of concrete with rough or smooth texture as desired. Vines can be trained over the masonry thus tying the bridge into the landscape (Fig. 5) in a way impossible in a steel truss which must be kept clear for periodical repainting. In a city a stone arch bridge may harmoniously continue the stone work of river or quay walls, parapets, and other masonry accessories; or it may be of the same stone as neighboring important buildings. Arch bridges are still built entirely of stone but more often of concrete faced with stone and most often of all entirely of concrete, either plain or reinforced.

Of the stone bridges the High Bridge over the Harlem in New York, with its numerous high arches and the the Cabin John Bridge near Washington, with its single wide span, are both deservedly admired; while the new bridge at Hartford, with its many granite arches, is very satisfactory in its carefully studied and intelligent simplicity. Locally there are, in the Metropolitan district, many bridges built either of the Roxbury conglomerate or of seam face granite (Fig. 5), both of which materials have the great advantage of looking old and mellow instead of raw and new like a freshly split granite, for instance. In a park, and especially in the more rural ones, newness obtrudes, and it seems much better to continue a road across any necessary hollows or rivers with as little change in color and material as possible. In such parks nature is preferable to art. Nevertheless one doubts the wisdom of using round boulders for bridges in cases where a stone with flatter surfaces to form good bed joints would give an appearance of much greater structural security. It would seem best to limit

the use of boulders to very small bridges and then only in the most picturesque rocky woodland surroundings. The boulders do not harmonize with the straight lines and mechanical exactness of buildings, walls, sidewalks, and other accessories in a thickly populated neighborhood.

The concrete bridge is now used in many forms. The simplest type is a monolithic structure without reinforcement, with a continuous soffit and with earth filling above the haunches to the level of the roadway, retained by spandrel walls which rise from the face of the arch. It seems logical in such a case to mark the thickness of the arch proper by slightly

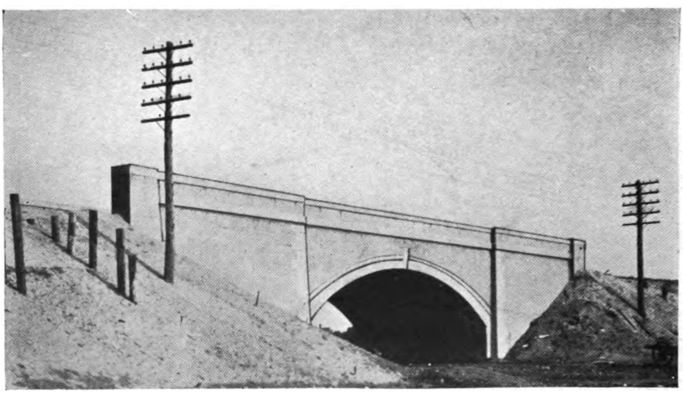


Fig. 6.

projecting it beyond the spandrel walls, or by carrying a slightly projecting band across at the line of the extrados. The structural arch is made thinner at the crown than at the springing, and thus gives curves of two different radii (Fig. 6). The spandrel wall thus defined may well have a different surface finish, as showing its different and less important structural function. Often the arch ring is hammered and the spandrel wall is given a rougher surface by washing the cement from the face of the concrete, exposing the aggregate. The architect and engineer now have the greatest variety of available surfaces for concrete. A very good surface is obtainable by using a gravel aggregate and washing or brushing off the surface cement. The gravel may be obtained or screened to any desired

size depending on the size of the structure and the distance of the surface from the eye and considerable variety of color is also possible.

The bridge, which carries the Southern Division of the Boston and Maine Railroad over the Mystic Valley Parkway, near West Medford (Figs. 6 and 12), is a good example of the contrast between a six cut arch ring and a coarsely picked spandrel wall. The spandrel wall in this case is of a warmer tone than the cast block arch ring; this tone being obtained by the use of gravel with many colors of stone. Crushed stone aggregates give a much less interesting surface than the pebbly surface of gravel.

A variety of concrete arch is now often made by facing the structural arch, which may be reinforced or not, with a cast concrete block face arch. Belts, parapet copings, balustrades, and quoins of piers are also made of these cast blocks. The method simplifies the matter of forms and also makes it easier to obtain a good surface on each block than if they were cast as a monolith in place. The blocks are sometimes set with ordinary mortar joints like stonework, and sometimes the face of the blocks is projected with channels between giving an effect of greater robustness. Sometimes this rustication is also carried all over the spandrel walls, as on the bridge at Sandy Hill, N. Y. *(Engineering News, May 9, 1907)*, but the peculiar shape of the spandrel walls leaves a number of triangular shaped blocks at the junction with the line of the extrados, and the rustication makes these small blocks all the more conspicuous and unpleasant. It is easy to make grooves and panels either in monolithic concrete or in cast block by nailing strips on the inside of the forms, but that is no reason that they should be carelessly or indiscriminately used. The same remark applies to pilasters, balustrades, and other embellishments. When used by an architect on an ornate bridge near rich architectural surroundings, they may be admirable, but the engineer, less experienced in their use, will usually get better results by keeping his structure simple. It may seem natural to make a cast block ring the same height as the structural arch behind it, but it is better to make it higher because the reinforced arch is so thin that an arch ring of equal height looks too attenuated for an unre-

inforced voussoir arch, and the voussoirs become too nearly square to look well. A voussoir two to three times as high as it is wide looks much better than one nearly square.

In the case of bridges of reinforced concrete the architect as well as the layman feels at first confused because here is a material which has an outward semblance to stone, but is used in forms much more slender than he is accustomed to in stonework; these slender forms being made possible by steel reinforcement which is entirely concealed. The engineer takes this slenderness as a matter of course, the architect feels that the concrete should be molded in some way to suggest that it is reinforced, and he feels that imitation joints especially when rusticated are entirely out of place.

Reinforced concrete bridges are built with continuous soffits and spandrel walls just as plain concrete or stone bridges are, but they are also, and more characteristically, built in the form of arches with open spandrels above the haunches instead of earth filling; and in place of the spandrel wall they have slender reinforced concrete vertical supports, extending from the arch ring to a flat floor at the roadway level. These vertical supports are most often united at the top by small arches. This arrangement of an arch with perforations above the haunches has the great æsthetic advantage of showing the structure of the bridge, with perfect clearness, something which the arch with plain spandrel walls does not so clearly do.

Another type of design which has some practical advantages divides the arch into two or more separate longitudinal arched ribs, rectangular in cross section, and the verticals resting on them are united transversely as well as longitudinally to support the roadway slab. Such a bridge with its quite elaborate system of main arched ribs, vertical supports, transverse and longitudinal beams, and arches and roadway slab becomes, in its complexity, much more like a steel framed structure than a stone structure; and its members are intermediate in size between the two. It is necessary to become accustomed to the proportions peculiar to the material. It will be most satisfactory if the reinforced structural parts are left plain, with no imitation of stone joints and no cast ornament.

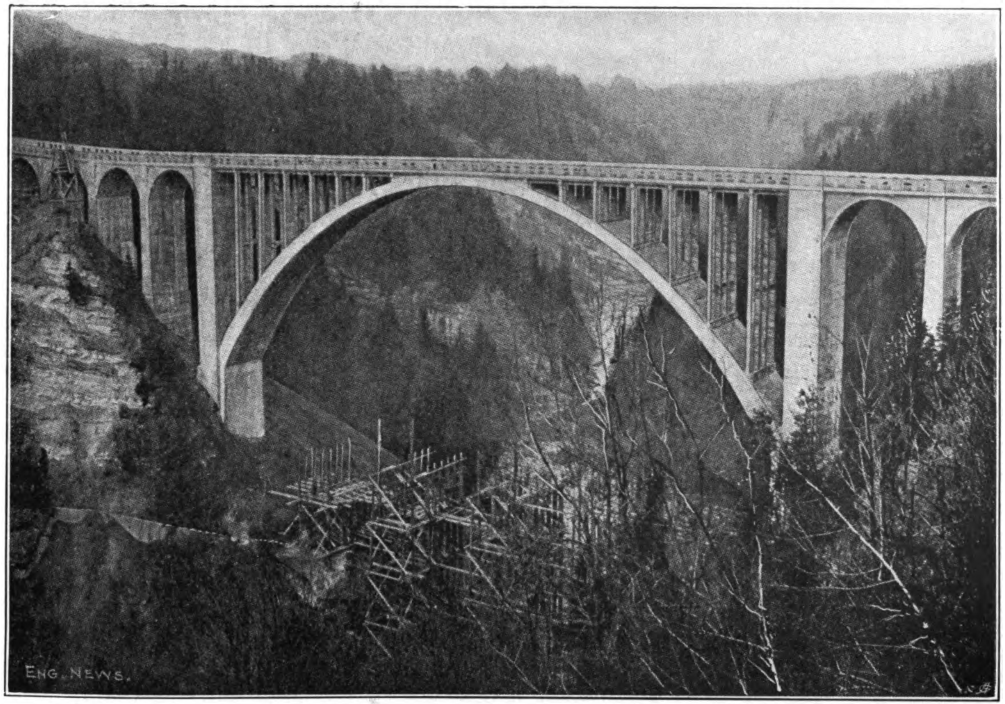



FIG. 7.—SITTER BRIDGE.
[Reproduced by courtesy of Engineering News, New York.]

The imitation of stone joints is evidently out of place in a material filled with continuous longitudinal reinforcement. In some cases bridges of this general type with open spandrels are built of separate voussoirs, cast in place, or of blocks resembling large voussoirs; alternate blocks being cast in place first, and the spaces between being filled in afterward, two at a time to keep the load on the centering symmetrical. In such cases there is no longitudinal reinforcement, and it seems harmless to add false joints in the large cast blocks to make the apparent voussoirs a better shape. In some cases also, the vertical supports from the arch ring to the roadway slab are in the form of some-

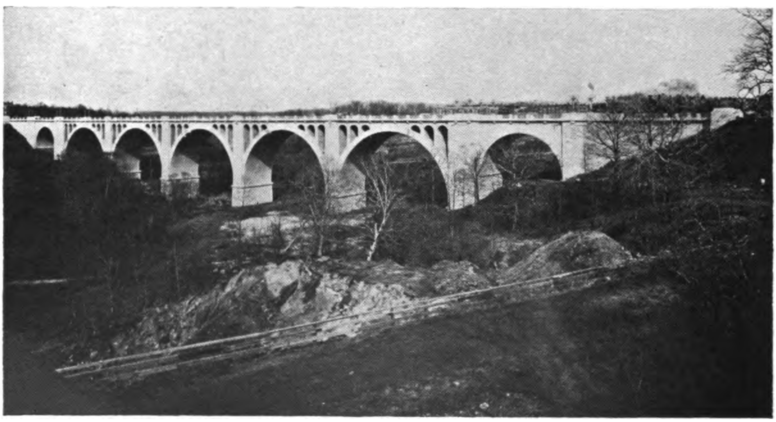


FIG. 8.

[Wm. J. Douglas, Engineer of Bridges. E. P. Casey, Consulting Architect.]

what heavy transverse walls not reinforced, instead of reinforced columns; and these transverse walls are sometimes lined to imitate joints, although with doubtful taste, as they are monolithic. The satisfactory appearance of these open spandrel bridges depends on the careful outlining of the arch ring, its proper arrangement at the skewback and the outline and spacing of the vertical supports with their uniting members. They should be given much study. The Sitter Bridge in Switzerland is a bridge of the slender reinforced concrete type; while Fig. 8, the Connecticut Avenue Bridge in Washington, shows the heavier proportions of the unreinforced type. The latter bridge has

the face ring of the arches and the quoins of the piers made of cast blocks, and is one of the many carefully designed bridges which adorn the city of Washington.

As to the curve of the arch itself, the environment may often fix this within close limits. Low clearance may make a segmental curve the only possible one — a deep ravine or valley may admit a semi-circular one. The ellipse is used a good deal, sometimes because a wide clearance is necessary and the engineer or architect does not like the appearance of a segmental arch springing from a vertical abutment, or because some prefer the outline in itself to the segmental. It is to be said that the segmental curve is structurally the best, that any arch tends

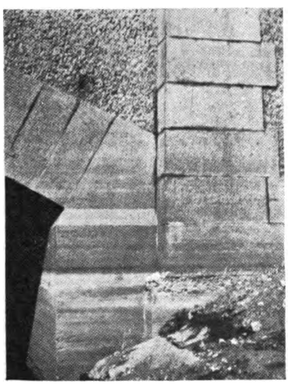


FIG. 9.

FIG. 10.

to rise at the haunches and the elliptical arch, unless very like a segmental one, is weak in that it departs from the line of pressure. In some cases the curve is a parabola which more nearly approaches the line of thrust than even the segmental, and gives a strong, handsome line. The bridge over Piney Creek at Sixteenth Street, Washington, D. C. *(Engineering News, November 16, 1905)*, is a good example. Catenary and three-centered curves are also used. The structural arch is always thicker at the springing than at the crown, and any face ring should follow the same outlines, the extrados and the intrados not being concentric. Where they are concentric the structure is not so clearly shown, and the parallel curves are not so interesting.

The skewback of a stone arch or of a cast block face ring requires careful design, especially where the curve is segmental. It should not be a triangular block coming to sharp angles at the corners. Fig. 9, for instance, seems much less satisfactory than either Figs. 10 or 11. Another arrangement often used, but always with poor effect, is to spring the arch from the side of the pier when the latter projects beyond the plane of the arch to form a bastion (Fig. 12). This shows no seat to take the vertical component of the arch thrust, and although the arch really springs from concealed skewbacks, the arrangement gives one the feeling that the arch may slide down the pier. The skewback is too important a member to be thus concealed. An

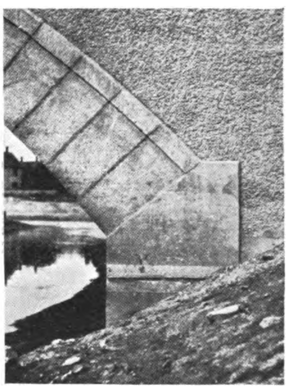


Fig. 11.

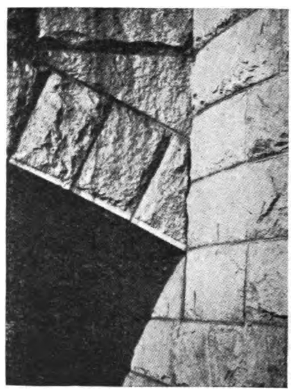


Fig. 12.

offset of the pier, flush or nearly flush with the face of the arch to receive the skewbacks, looks much better (Fig. 13), although the sharp angles of the skewback are not pleasant in this particular example.

In considering the component parts of a bridge, other than the arch or truss itself, the most important is the pier. This may rest on the shore or in the water. In the latter case a cutwater up to a level above high water is a necessity in currents of any force, especially where carrying floating ice and logs. The cutwater also serves to reduce the interference of the pier with the current to a minimum, and thus reduces scour around the foundations of the pier. One common form of pier which has been developed to hold steel spans is simple and good-

looking. This type is a long rectangle parallel with the current and with cutwater pointed in plan in two arcs of circles or in two inclined planes. Above the cutwater the ends are square or rounded, and the whole pier is battered from bottom to top. The type so evidently and simply fufills its purpose that it can be improved very little. The piers of masonry arch bridges are naturally made wider than those supporting steel spans, and often have the cutwater continued above high-water mark in the form of a rectangular, octagonal, or semi-circular bastion around which the parapet or balustrade is carried. If the bridge is used by pedestrians this projecting bastion gives a chance for a seat and a point of observation, out of the way

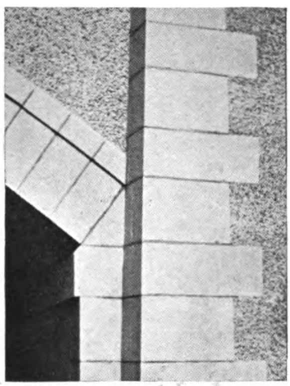


FIG. 13.

of regular traffic, as on the West Boston Bridge. On a bridge carrying a railway only, such projecting bastions are uncalled for by any practical demand, and a small projection marking the width of the pier seems all that is required to properly emphasize it. In concrete it is possible to merge the cutwater by graceful curves into such a small projection as is very well shown in the piers of the Maumee Bridge at Waterville, Ohio (Fig. 14), the form being one that seems just natural to a molded material like concrete, and not one that would be done in stone.

The problem of a balustrade or parapet for the sidewalk seems best solved by a solid parapet, with a projecting belt to mark the level of the walk and a simply projecting coping at

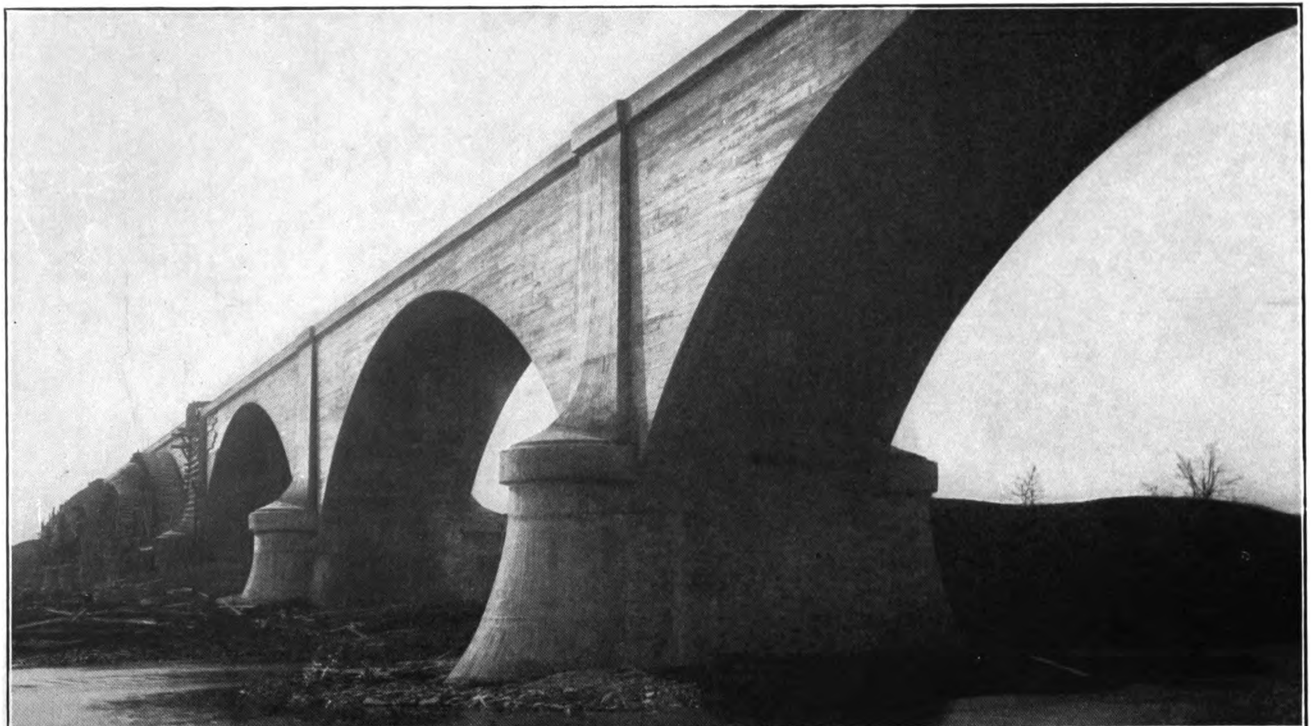


Fig. 14.
[Published by courtesy of the National Bridge Co.]

the top. Only the most elaborate bridges require stone or concrete balusters between molded and panelled posts, and where these are required the engineer will do well to call in the architect who, from his greater experience with such details, is more likely to get them right. Concrete balusters are sometimes made in imitation of stone. Balusters of stone are turned in lathes, while those of concrete are cast in molds. The very different method would seem to suggest a different shape, and various designs have been built departing from stone precedents, although not always with success.

Least satisfactory of all is the pipe railing sometimes used on cheap work. Unless very heavy, it looks too flimsy for the

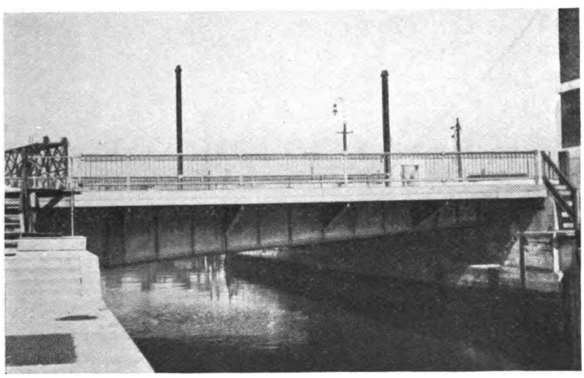


Fig. 15.

solid masonry which it crowns. On the whole the engineer is probably wisest when he uses a simple parapet of stone or concrete.

In a class by themselves are the various types of bascule bridges now much in use for draws. The span may be either a plate girder or a truss. The girder, especially when the deck form can be used, is much less conspicuous and homely than the through truss with its ugly top chord outline. The deck plate girder type is well shown by the rolling lift draw over the lock in the Charles River Dam (Fig. 15), while the through trusses are used to carry the railroad tracks over Fort Point Channel in Boston.

Closely akin to the subject of bridges is the design of elevated railway structures. The subject is too large to be considered here, but it seems worth while to show a view of the new structure of the Boston Elevated Railway at Forest Hills (Fig. 16). The highway, with the elevated structure, crosses a five-part parkway on a skew. Close by, the parkway is carried under a railroad through five stone arches. If the ordinary two-post steel bents had been used for the elevated structure,

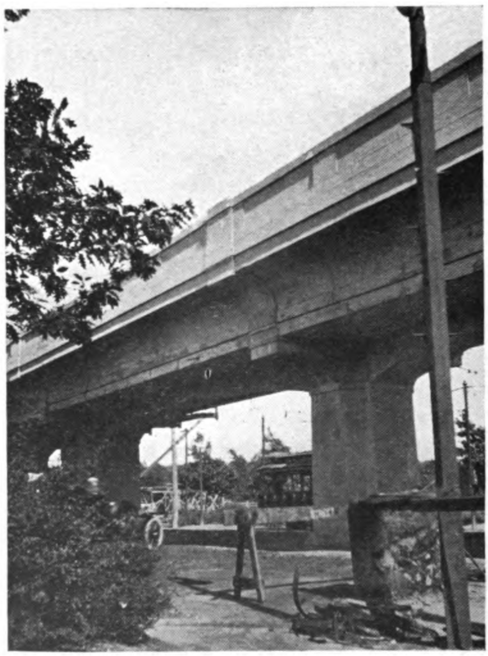


FIG. 16.

the posts must have been skewed either to the highway or the parkway. The architectural advisers of the company suggested a structure balanced on a line of single posts, one opposite each pier of the stone arches adjacent, as avoiding the awkward skewed posts, and the steel structure is clothed in concrete to harmonize with an adjacent concrete elevated station, to lessen noise, to eliminate painting, and for appearance sake where crossing a fine parkway.

The arrangement is interesting not only as solving a particular problem, but as suggesting a structure which might be built anywhere else with perhaps more slender posts of reinforced concrete, and with the rest of the structure built of reinforced concrete instead of steel encased in concrete as here.

The reader will notice the continual use of the word "simple" in these notes, but it has been used no more than it deserves. The simplicity of a bridge should not be the bald ugliness of a coal-hoist, but should be the carefully thought out simplicity of a tailor-made gown or of the smoothly flowing language of a book which has been corrected word by word to reach its final form. If the engineer is to obtain this simple beauty he must in the first place appreciate the desirability of it, and then he must study the effect of various arrangements of the structure on its final appearance as carefully as he analyzes the stresses. He should use no ornament which he does not understand, any more than he would introduce unnecessary members whose action he cannot analyze.

If an architect is to work with the engineer in making a worthy bridge, he must be a man who has an appreciation of structural forms as well as an artistic imagination, and he should also have a knowledge of the successful bridges already built, and be capable of analyzing the elements of their success.

The opportunity to design a bridge, which shall be for years not only a convenient and safe way but also an object of dignity and beauty giving pleasure to every observer, ought to inspire any engineer or architect to his highest effort.

# DAMS FOR THE CATSKILL WATER WORKS

BY ALFRED D. FLINN

Engineer of Headquarters Department, Board of Water Supply

Catskill Water Works, for augmenting the municipal supplies of New York City, no longer need lengthy introduction to readers of the HARVARD ENGINEERING JOURNAL. Four years ago the Board of Water Supply began final surveys and designs for this system of reservoirs and aqueducts to furnish, from the Catskill Mountains to the metropolis, a large additional supply of wholesome water. One branch of these surveys was described in the JOURNAL for June, 1908, by Mr. James F. Sanborn (Lawrence, '99), under the title: "Some Geological Features Affecting the Catskill Water Supply." Surveys for the development of the first watershed, that of Esopus Creek, and for the great aqueduct have been substantially completed; designs for the major portion of these works have been very far advanced. Active construction was begun on the aqueduct early in 1907, and in the fall of the same year on the main dams of the principal reservoir, the Ashokan, near Kingston, N. Y. Successive contracts have been let until now fifteen large contracts are in force, amounting to $43,000,000 and covering the aqueduct from Ashokan Reservoir to White Plains, with the exception of a few small gaps, together with the greater part of the work connected with Ashokan Reservoir. Since a full general description of the system was published in the *Century Magazine* for September, it is unnecessary to go into further detail here. Many parts of these works are full of engineering interest; this article, however, will be restricted to a brief discussion of the principal dams.

To impound the 128,000 millions of gallons of water in Ashokan Reservoir, there are required to close the gaps in the rim of the natural basin dams aggregating 5.1 miles in length; there are also a dividing weir and dike 2,200 feet long separating the reservoir into an east and a west basin. Kensico storage reservoir of 40,000 million gallons capacity requires a masonry

dam 1,830 feet long and a dike 1,400 feet long, besides two temporary dikes 1,000 feet long. Hill View distributing reservoir necessitates 9,000 feet of continuous earth embankment, surrounding and supplementing in depth the excavated portion of the reservoir. Put end to end, all these dams would extend 7.4 miles; they will contain approximately 15,000,000 cubic yards of materials. Olive Bridge Dam, the greatest of the dams of Ashokan Reservoir, will be 4,850 feet long on top, embracing

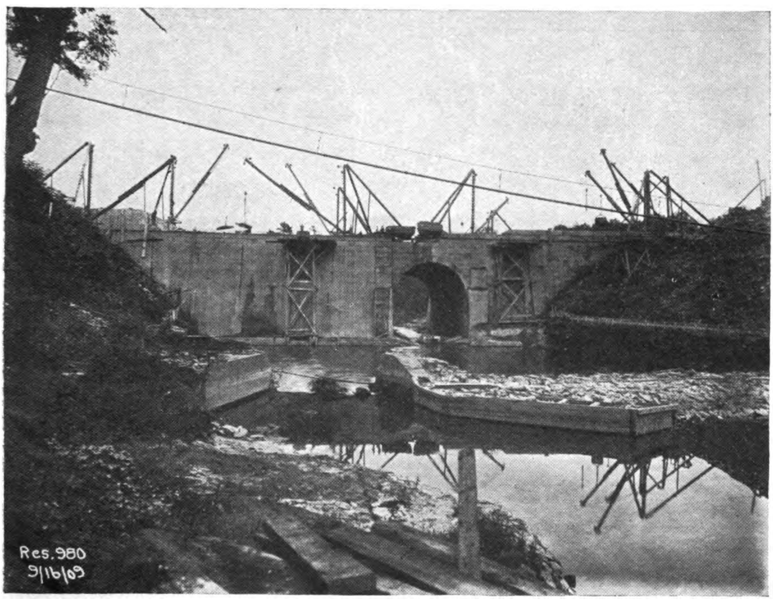
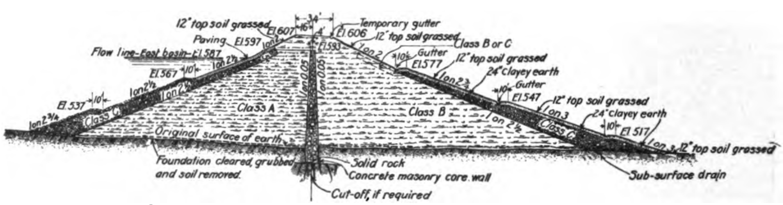



FIG. 1.
OLIVE BRIDGE DAM, MASONRY SECTION. UPSTREAM FACE.
SEPTEMBER 16, 1909.

a central masonry gravity section 1,000 feet in length, with a maximum height above the lowest foundation excavation in the rock of 240 feet. Kensico Dam will have a maximum height of nearly 300 feet, estimating from the condition of the rock foundation as disclosed by the diamond drill exploration.

Among all these dams there can be distinguished three distinct types: the rolled earth embankment, the gravity masonry impounding dam and the masonry waste weir. Accompanying

illustrations show cross sections of each type. All the reservoir sites afford excellent materials for earth dams or dikes. The highest of these will be 110 feet above the present surface of the ground, and will restrain 90 feet of water. As may be seen in the drawings, the dikes have generous top widths and liberal slopes, which latter are made flatter toward the bottom. The thickness of the dikes is further increased and the slopes broken by berms 10 feet wide at vertical intervals of 30 feet. The tops of these dikes are usually 20 feet above full reservoir level, and their thickness at this level is 114 feet; the highest dike is about 800 feet thick at its bottom. Each dike has a dense concrete corewall at or very near its middle, 4 feet thick at its top, a little above full reservoir level, with a batter on each side of 1 on 0.05. Corewalls usually start in trenches cut into the rock, so as to prevent flow of water along the




TYPICAL CROSS SECTION OF DIKE

Fig. 2.

surface of the rock beneath the dam. In some places, however, where the ledge-rock lies at great depth, and the overlying material is very compact and impervious, the excavation is not carried to rock, but simply well into the impervious boulder till.

On the upstream side of the corewall the earth is carefully selected and spread in thin horizontal layers which are about 4 inches thick after rolling, stones larger than 3 inches being thrown out; on the downstream side the layers are 6 inches thick and the earth preferably more porous. On both sides the earth portion of the embankment is covered with a thick layer of stones culled from the earth or obtained from the rock excavations. As a protection against ice and waves a heavy stone paving is laid from a level 20 feet below full reservoir to 10 feet above. The upper portion of the water

slope, the top and the downstream slope are covered with earth and grassed, excepting that in some cases a highway is to be built on the top. Gutters along the inner sides of the berms collect the rain-water falling on the grassed slope and convey it into pipe drains, thus preventing serious erosion of the slope which would otherwise occur. All trees, bushes, top-soil and other unsuitable materials are removed from the site before starting an embankment.

The waste weirs are of concrete or cyclopean masonry, according to their size, founded on solid ledge-rock, and have ogee downstream faces. They are designed to pass safely water several feet in depth over their crests, and are so proportioned that the sheet of water will always be in contact with the face until it passes off into the channel at the toe.

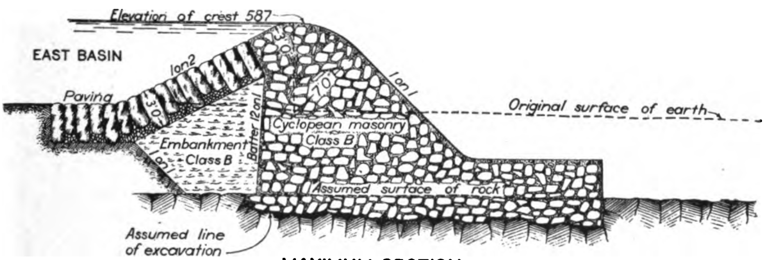



FIG. 3. WASTE WEIR.

Olive Bridge and Kensico Dams are both to be of cyclopean masonry, the former faced on both sides with cast concrete blocks and the latter with granite on the exposed portions of the downstream face, but concrete blocks elsewhere. Both dams are designed to resist very safely water at a level several feet above full reservoir, together with an upward pressure on the bottom, due to penetration of water into the seams of the rock; also to withsand an ice thrust of 20 tons per linear foot of dam, with the water at full reservoir level. Indeed, these dams are designed to be abundantly safe against any force or combination of forces which can be even remotely assumed to occur. Olive Bridge Dam will have a minimum thickness at the top of 23 feet, and its top will be 20 feet above full reservoir. Kensico Dam will have a minimum thickness of

28 feet but, owing to certain local conditions, its top will be only 15 feet above full reservoir. Each will carry a highway across the valley.

Into the designs of Olive Bridge and Kensico Dams two or three novel features have been introduced. Irresistible forces, due to temperature changes, have quite universally caused transverse cracks in masonry dams of any magnitude. Such cracks are seldom serious, but are unsightly and permit slight leakage. Quite commonly too, water, forced by the pres-

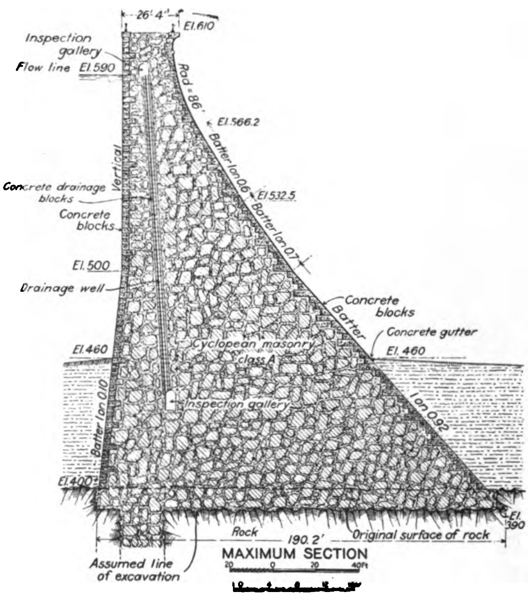



Fig. 4. OLIVE BRIDGE DAM.

sure caused by the great depths back of such dams or drawn by capillary action in the masonry, has seeped through the masonry more or less copiously. Seepage disfigures the face and with the frost disintegrates slowly the masonry at the face of the dam. Structural remedies for these troubles constitute the unusual features.

Observations showed that masonry dams had cracks at intervals of from 40 to 100 feet approximately, determined apparently by size and other conditions of design and location.

In at least one instance in this part of the country such cracks had occurred in a large dam in spite of reinforcement with large steel bars in the upper part of the dam. It was, therefore, determined to provide artificial cracks; *i.e.*, expansion joints, at intervals of 80 to 85 feet in the Olive Bridge and Kensico Dams. These joints will extend from near the foundation to the top and from face to face, thus dividing the dam into sections, any one of which may be built in advance of others, if so desired for convenience. An expansion joint is

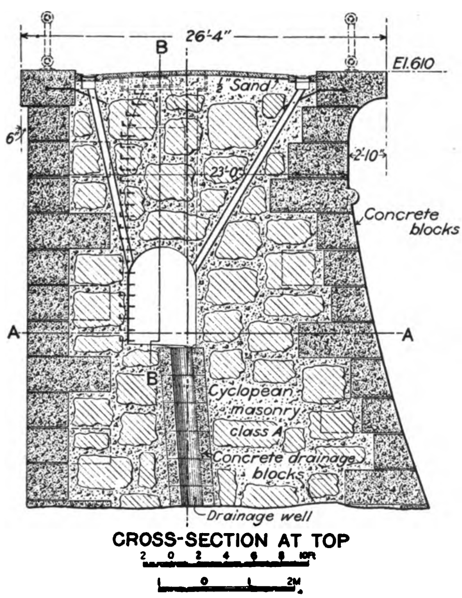



Fig. 5. OLIVE BRIDGE DAM.

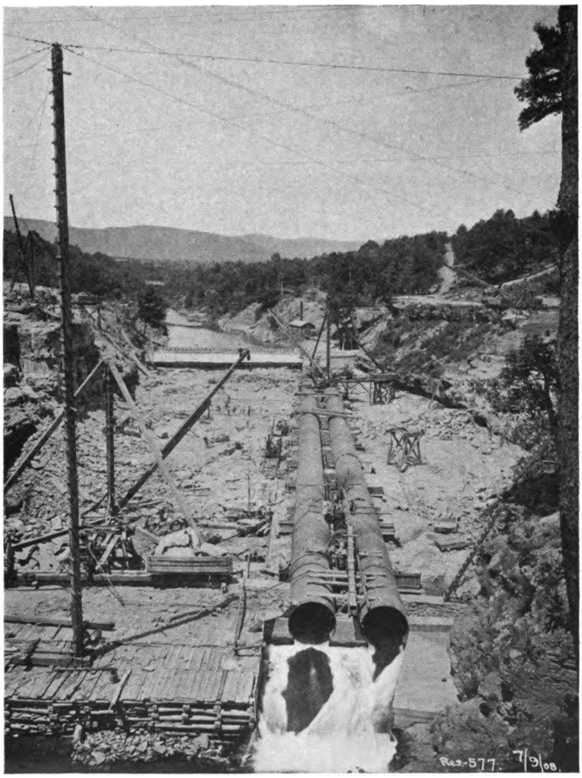
not simply a plane crack clear through the masonry; it is made up of tongues, or keys and grooves which offer effective resistance to the flow of water. Most of the keys have their sides slightly beveled, but one, near the up stream face, has its sides very carefully made parallel to the axis of the dam. With the contraction due to the initial cooling of the masonry the beveled keys will open very slightly, but the other should slide with its faces in contact with the adjacent masonry. To accomplish this latter, without cracking through the tongue, will

require very careful work; the other tongues are beveled to avoid this risk more easily. The side of an expansion joint built first is made with smooth-face concrete blocks, and before the adjoining section of the dam is built, the contact face is coated with some inadhesive substance, such as coldwater paint or asphalt. Near the upstream end of each expansion joint a large vertical well is formed to afford access for inspection, and permit any water, which may get through the joint thus far, to fall into a drainage gallery in the lower part of the dam. Subsequently these wells may be filled with masonry arranged in such a way that if it should crack through, the crack will be obstructed by a diaphragm of copper, continuous from top to bottom, which can suffer the slight movements of expansion and contraction without being torn or otherwise ruptured.

To intercept seepage, which may penetrate the masonry between expansion joints, drainage wells, 16 inches in diameter, are being built into the masonry about 12 feet apart, near the upstream face, as shown in the cross-section of the dam. These wells all terminate in the lower drainage gallery, from which a transverse gallery leads to a drain at a convenient place on the downstream face of the dam. Along the tops of the drainage and inspection wells another longitudinal gallery, in the upper part of the dam, affords opportunity for inspection and cleaning. To build these drainage wells so that they would collect the water as readily as possible, would not get stopped by mortar or other material or by being thrown out of line, and would not seriously interfere with the operations of placing masonry, was something of a problem. The solution was found in cubical porous concrete blocks, 3 feet square and 2 feet 5 inches deep, with the 16-inch bore formed in them at the right inclination. These can be built into the masonry like any stone and a simple stopper, always kept in the top block of each well, prevents things from falling in. Alignment is easy and slight inaccuracies are not serious.

Dam sites were all thoroughly explored to considerable depth by wash borings and diamond or shot drills, furnishing cores of rock from about 1 inch to 3 inches in diameter.

Esopus Creek, at the site of Olive Bridge Dam, flows through a rock gorge about 40 feet deep and 200 feet wide. As a preliminary to the beginning of masonry construction, a coffer-dam was built across the gorge above the site of the dam and another a short distance below. Between these coffer-dams two 8-foot steel pipes were laid which carried the ordi-




OLIVE BRIDGE DAM. MASONRY SECTION JULY 9, 1908.

nary flows of the creek, permitting the space between the coffer-dams to be unwatered and the excavation of loose and unsound rock to be made. A few moderate floods overtaxed the pipes and filled the excavations, necessitating re-pumping of the space between the coffer-dams. After the masonry had been brought up to the level of the bottoms of the pipes, a large arched con-

duit was formed through the dam, through which the water of the creek — even the most extreme floods — can safely pass until the dam is sufficiently completed to begin storing water in the reservoir, when this conduit will be closed at a period of low water. As soon as the lower part of this conduit had been formed, the water was turned through it and the 8-foot pipes removed. Two stages in the progress of construction of this dam are shown in the accompanying views. Work is now in progress throughout the full length of the dams and dikes, and the contractor's methods and extensive plants are full of interest.

The construction of the Catskill Water Works is being carried out by the Board of Water Supply of the City of New York, composed of three commissioners: John A. Bensel, president; Charles N. Chadwick, and Charles A. Shaw. J. Waldo Smith is chief engineer, Charles L. Harrison, deputy chief engineer; Carleton E. Davis, engineer of the Reservoir Department, including the Ashokan Reservoir; Merritt H. Smith, engineer of the Southern Aqueduct Department, including Kensico Reservoir and dam; and Robert Ridgway, engineer of the Northern Aqueduct Department.

# HARVARD ENGINEERING JOURNAL

A Quarterly

DEVOTED TO THE INTERESTS OF ENGINEERING AND ARCHITECTURE AT HARVARD UNIVERSITY

THE OFFICIAL ORGAN OF THE ASSOCIATION OF HARVARD ENGINEERS

Published four times during the college year by the Board of Editors of the Harvard Engineering Journal.





### Subscription Rates

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| Per year, in advance . . . . . . . . | $1.00 |
| Single copies . . . . . . . . . . | .35 |

Address all communications:—
Harvard Engineering Journal,
Room 218. Pierce Hall.
Cambridge, Mass.

Entered at the Post Office, Boston, Mass., as second-class mail matter June 5, 1902.


## ASSOCIATION OF HARVARD ENGINEERS

The Association of Harvard Engineers at their last annual meeting, held in the spring, voted to authorize the Council of that organization to make arrangements whereby the Harvard Engineering Journal should become the official organ of the Association. The Council, at a meeting held in June, empowered the Secretary to negotiate with the Journal toward this

end. At the first fall meeting of the board of editors, an agreement was made with the Secretary, so that the JOURNAL becomes, with this number, the official organ of the Association.

Acting in this capacity, it is proposed to have a department of the JOURNAL devoted entirely to the affairs of the Association and supervised by a member of that body. It is further proposed to establish a bureau, by means of which members of the Association, who are applicants for positions, may communicate with members who know of opportunities for employment. With this end in view, all members who know of opportunities for employment and those who are seeking such opportunities, are urged to communicate with the Secretary of the Association, F. L. Kennedy, 43 Appleton Street, Cambridge. In the near future, definite plans will be made in regard to the above propositions.

Meanwhile, in the hope that all graduate subscribers may become members of the Association, application blanks for membership are being sent out with this issue. More membership blanks may be secured, if desired, on application to the Secretary.

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## CONTRIBUTION OF ARTICLES BY MEMBERS OF THE ASSOCIATION

The members of the Association can assist the editors in a number of ways to make the JOURNAL of value, not only to the Association, but to its other readers as well. Perhaps the most important of these ways is the contribution of articles on subjects of engineering interest. Therefore, the members of the Association are urged to confer with the editors in regard to prospective articles. That the Association has already begun to show an interest in the JOURNAL is manifested by the fact that all four contributors to this number are members. It is to be hoped that the other members will show an equal interest.

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## ENGINEERING SOCIETY

The first meeting of the year was held November 1, in the assembly room of the Harvard Union. Previous to the gen-

eral meeting, the executive board met to act upon the resignation of Warren B. Strong, as president. Hugh Nawn was elected president, and George W. Lewis was elected secretary, to succeed Mr. Nawn, who had formerly held that office.

The general meeting was called to order by Professor Adams, who turned the meeting over to the new president. Professor Clifford, the first speaker, talked interestingly upon the improvements in electric illumination, power production, and transportation, during the last twenty years. Professor Johnson, as the oldest member of the department of engineering, followed with reminiscences of the old Lawrence Scientific School in the late eighties. Mr. James V. Martin spoke briefly upon the formation of an aeronautical society at Harvard, to experiment with as well as study aviation. Prof. G. A. Young, of Purdue University, now studying in the graduate School of Applied Science, described briefly the scope and aims of the engineering department at Purdue. Professor Adams, the last speaker, talked upon efficiency in human endeavor. After the speaking, an informal hour was enjoyed by the members and professors present.

## CIVIL ENGINEERING CLUB

The Civil Engineering Club held its first meeting of the year on October 14, in the Assembly Room of the Harvard Union. The attendance showed an increase of about fifteen men over last year. Informal talks, containing much sound advice, useful to the club and its members, were given by Professors L. J. Johnson, C. W. Killam, H. J. Hughes, and Mr. Paige. After the speaking, refreshments were served, and the new members were introduced to the older members of the club and to the members of the Faculty. Much enthusiasm was manifested at this first meeting, and the club seems to be in a position to have a very successful year.

THE OFFICIAL ORGAN OF THE ASSOCIATION OF HARVARD ENGINEERS

JANUARY, 1910

# HARVARD ENGINEERING JOURNAL

A QUARTERLY
DEVOTED TO THE INTERESTS OF
ENGINEERING AND ARCHITECTURE
AT HARVARD UNIVERSITY

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# NOTICE

The annual joint dinner of the **HARVARD ENGINEERING SOCIETY** and the **ASSOCIATION OF HARVARD ENGINEERS** will be held on **MARCH 12, 1910**, at 7 o'clock in the **HARVARD UNION**.

*Frontispiece.* FIG. 1 [Forest Hills Terminal]

COMPLETED STATION FROM THE NORTH-WEST, SHOWING ARBORWAY AND RAILROAD BRIDGE

HARVARD
ENGINEERING JOURNAL

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Devoted to the interests of Engineering
and Architecture of Harvard University

The Official Organ of the Association of
Harvard Engineers

VOL. VIII JANUARY, 1910 NO. 4

# THE PROCESSES IN COTTON-SPINNING

BY LEON A. HACKETT, S.B., '04

The cotton manufacturing industry of this country has an annual production of nearly half a billion dollars' value, 33 per cent of which originates in the State of Massachusetts alone. The industry, while expanding as a whole to meet future requirements, has nevertheless fallen off in Massachusetts during recent years in its percentage growth, when compared with other sections of the country, and indeed with the prospect now that the center of the industry will eventually move to the South.

The increase of fixed capital, in fact, during the past eight years, for Massachusetts has been but about 20 per cent, while for the South, in a corresponding period, the increase has been well over 140 per cent.[1] This shows that the manufacturing output for home and export trade is far from being abreast with the demand for goods, and further indicates that the deficiency in production of this principal staple manufacture of the state is to be supplied from another locality.

With a view to giving some general idea of the manufacture of cotton, an industry in which Massachusetts has long been foremost, the following is presented, being, however, only an outline of the operations in that branch of cotton manufacture concerned in the production of cotton yarn from raw cotton. To the average reader, unacquainted with the manufacture of

[1]Census Report, Bulletin 97, p. 12. This does not include 1909.

this particular staple, an explanation of cotton-spinning as a whole is of first importance, one that does not enter elaborately into details, but gives a notion of what is accomplished in the factory, and what machines and materials are used, and what principles are involved in the various stages of progress. In such an explanation as this there will necessarily be introduced some few technical terms peculiar to the particular process described, without which the explanation would be less intelligible.

In the spinning of cotton yarn there are five processes, or really five types of machines, through which the cotton must

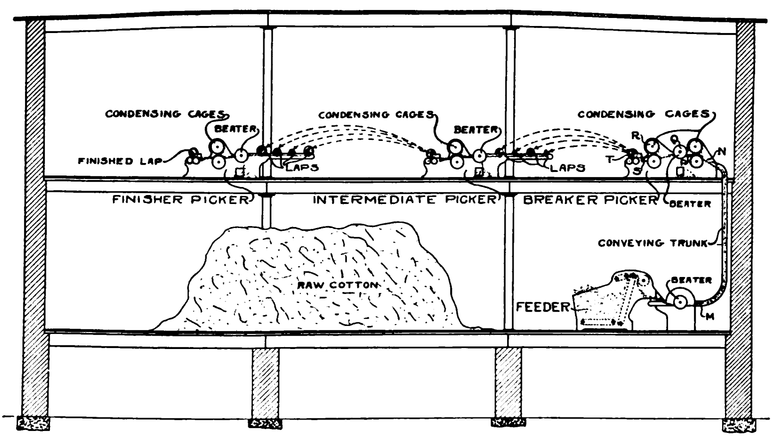



FIG. 1

pass in its manufacture into yarn. These processes are the picking, the carding, the drawing, the process using the machine called a roving-frame, and the final process of spinning proper.

## PICKING

The picking process, which is the first to handle the cotton, has two purposes, — first to clean the cotton of its broken leaf, sand, and very short fibres, and then to prepare the cotton into a suitable shape to be treated in the next process of carding. Four machines are used successively to do this, which are shown in Fig. 1, in the order of their working, as feeder, breaker picker, intermediate picker, and finisher picker.

Cotton, as received at the mill, comes in the form of bales approximating 500 pounds in weight, compressed to about 16 pounds per cubic foot. From this previous treatment the fibres have become pretty well matted together, and when they arrive at the mill and are opened up, they do not return to their natural fluffy state without considerable mechanical handling.

The feeder (Fig. 2), which is the first to operate after the sacking and bale-ties have been removed, is designed to break up the cotton into comparatively small pieces from the

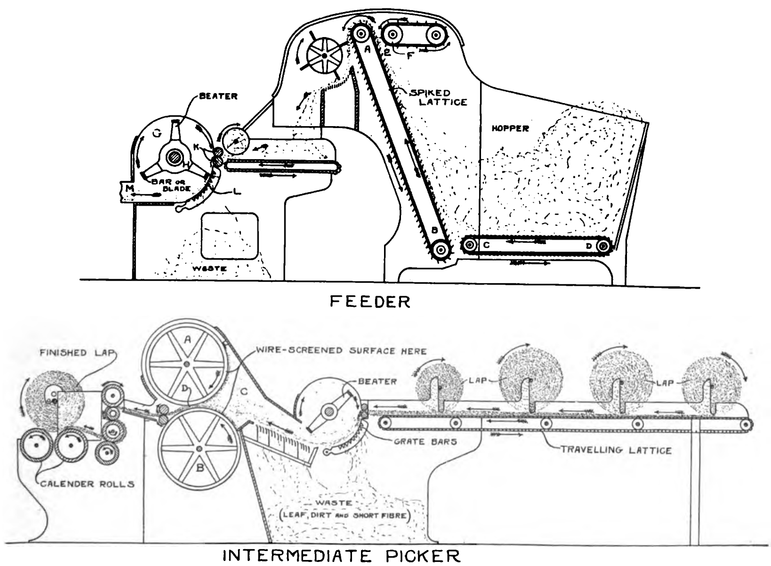



Fig. 2

large matted ones that are thrown into the machine hopper by hand from the mixing pile. The large pieces get tossed about in the feeder and come finally into contact with the spiked travelling lattice AB moving up the side of the hopper-box, to which they are carried forward by the other lattice CD moving along the bottom. As the cotton is carried forward to the spikes, some pieces are caught there of larger size than permit their passing by at the space E, and in consequence are knocked back by the revolving spiked roll F. Later these pieces again repeat the climbing-up operation, until the stock has been so

disintegrated that it is all enabled to pass on. It will be noticed that this knocking back of the large pieces of cotton during the action of the feeder is virtually a regulating action to the supply. The cotton next enters what is called the beater-chamber at G.

This is a cylindrical chamber containing the beater H, which is the vital part of the machine. In construction, the beater is simply three parallel bars fixed, and so bolted securely to arms about a center that they may be revolved at a high speed of 1,500 revolutions per minute. As the cotton is fed out from the rolls at K, it immediately comes in the path of these revolving bars, and in so doing is dashed down against some grate-bars at L. These bars are so arranged that while the cotton is opened up by them, the heavier impurities like sand, broken leaf, and seed, are also driven off and out between them, while the main bulk of the cotton passes on into a pipe or trunk M.

A suction fan is the means used to send the cotton on through the trunk to N (Fig. 1), where the cotton arrives at the next machine, usually located on the floor above, called the breaker picker. In this machine the cotton undergoes four distinct operations, the first of which might be called a condensing action, as the cotton enters from the end of the trunk; then there is the one of beating, as before in the feeder, following this another condensing action, and lastly the formation of a lap. The condensing action will be more clearly shown by reference to Fig. 2, the intermediate picker machine.

Two horizontal screened cylinders called cages (A and B) here revolve in opposite directions about twice a minute. The length of these cages is 40 inches, and their ends are so mounted in the sides of the machine that by means of an air-duct not indicated, leading from the ends of the cylinders to a suction fan, a pressure slightly below atmospheric is produced, so that the cotton as it enters the chamber C is at once attracted here to cover up the slowly moving screen surfaces. At the point D, as the cages continue to turn, the seal of the air chamber is passed, and the cotton peels off in the shape of one thick ribbon from both screens. In the breaker picker (Fig. 1) this condensing action is the same.

Now we will return to the point where the cotton from the trunk M passes on to N. Here it is condensed momentarily into a short ribbon (P), then an instant or so later it enters the chamber Q to be broken up by the beater, and finally is condensed again at the cages R, when it peels off into a ribbon at S. It passes now in and out around some heavy rolls and is wound up in a roll at T. In this form of a roll, the cotton is called a lap, being a huge wound-up ribbon of cotton 40 inches wide, 50 inches or more in length, and of weight from 40 to 50 pounds.

As a result of these two operations in the feeder and the breaker picker, the cotton is somewhat the cleaner and is in a form convenient for handling, namely, a lap. The laps which are formed in the breaker picker are next taken by hand and placed on the travelling lattice at the back of the intermediate picker. Four of these laps unwind together, pass on to the beater for the extraction of more dirt, and then are returned into lap form as before at the front of the machine.

The above constitutes the complete series of operations of the picking process, but for further cleanliness and for uniformity in the lap the intermediate picker and the next machine to follow, called the finisher picker, are used.

## Carding

The treatment of the cotton in the carding process is one tending towards the individualizing of the fibres; that is, a process where the cotton is so closely dealt with that the fibres may each be said to have been separated once during contact with the operative part of the card. The process by which the fibres undergo this minute handling is of the nature of a brushing or combing action, where all the fibres are subject alike to the same treatment with combs. This brushing action, too, instead of being repeated over and over again, is continuous, and the fibres are held fast at one end during the treatment only through embedding in the bristles or teeth of one brush, while another performs the combing or individualizing. The degree to which the fibres are actually individualized into what might be called parallel order, such as will be needed

later for the formation of the thread, is probably very small, but they are sufficiently loosened up here to adapt themselves readily to this order in the next operation.

The combing action, as used in the card, is indicated in Fig. 3, where the bottom comb or carding surface A of the cylinder acts as a carrier of the fibres bodily forward, to meet continually new clean bristles, or teeth, of the top comb or flats, and also to hold the fibres sufficiently embedded in the teeth so as not to slip by easily from one tooth to another during the operation here. When the cotton fibres are placed between the two brushes or carding surfaces of the

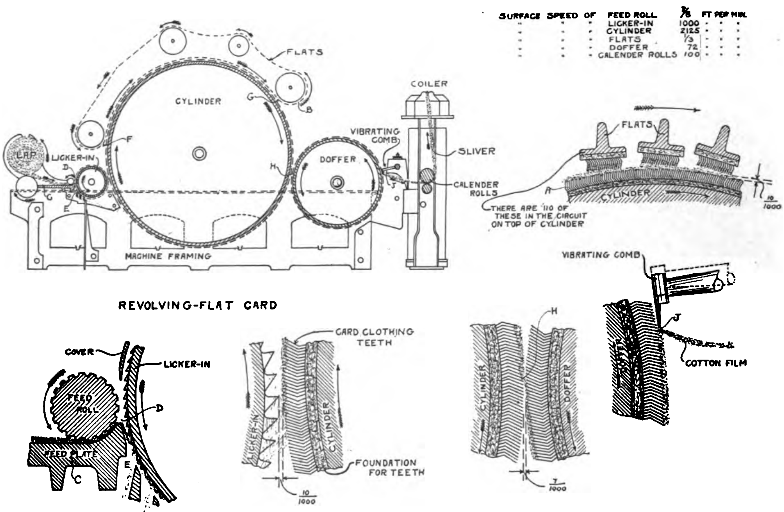



FIG. 3.

machine of this process, the straightening and isolating action is at first a gradual one, as the brushes move by one another, but after contact with the upper brush has continued for a moment, there becomes a distinct betterment in the order of the fibres. It will be seen from the figure that the spaces between many of the teeth of the upper surface are filled, or partially filled up, and the representation here is that of the extremely short fibres, which have been caught in these upper carding points of the flats, as they are called. These fibres constitute undesirable stock, which should be removed from the cotton, as

they would work poorly in the spinning operation later. The reason why these short fibres in the flats are detrimental to the finished yarn is that they are the immature cotton fibres, which are always present to a more or less degree in all grades of cotton, and as such do not possess the convolutions, or twists, in the individual fibres that the ripe ones do. These convolutions, or twists, in the fibres serve the purpose of interlocking with each other, and by so doing give the strand some appreciable strength (see Fig. 9).

An arrangement in the carding-engine provides for the removal of the short fibres through cleaning the flats as they turn, in course of their slow rotation, out of contact with the cylinder at about the point B.

A general description of the card may now be given, and the passage of the cotton followed through the machine at the same time. A card, as used in cotton manufacture, is a machine that has many of its active contact points concealed from view, so that when observed casually its means of operation are not at all apparent. In Fig. 3 a sectional view is given, and also enlarged sections of operative parts connected therewith.

The form in which the cotton is received in this process has already been stated as that of a broad rolled-up ribbon of cotton, or a lap, and now as it leaves the card it takes the form of a strand an inch or more in diameter. From the lap that is fed into the card, each yard is turned into from 100 to 120 yards of cotton strand of soft rope form, this number of yards with corresponding diameter being governed largely by whether the ultimate yarn is to be a coarse or a fine one.

The lap is placed at the back of the card and unrolls along the feed-plate C, until the end of the lap reaches the point D. At this point the cotton is snatched away in small tufts by the saw-toothed surface of a cylinder, revolving very quickly, which is called a licker-in. These little tufts of cotton which the saw-teeth pick off are dashed down against some grate-bars, or knives, at E, and at the same time any dirt still retained in the lap is driven out between the bars. The licker-in saw-teeth also throw the fluffy cotton down farther upon the cylinder, where it at once adheres, through the action of induced air-currents. At the cylinder the operation of the card may

be said fairly to commence, the licker-in being essentially a feeding and opening-up arrangement preparatory to the carding of the cotton proper. This main cylinder and operating part is usually about 50 inches in diameter and 40 inches wide, and is made of cast iron and provided with an axle for its rotation. It is also covered with a so-called card-clothing, the action of which is the direct means for combing and separating the fibres. In appearance the card-clothing is somewhat like a music-box cylinder, only the points on the latter are spaced far more coarsely than those of card-clothing on the card-cylinder. An enlarged section, given in Fig. 3, shows plainly the clothing teeth, as attached to the cylinder, the flats, and the doffer, and also the relative positions of these teeth when the cylinder is working against the flats or the doffer. The number of points in the card-clothing runs about 65,000 per square foot, and on the basis of calculated surface-speeds, there are from 10 to 15 points presented for every fibre that passes through the machine, and this, in view of the purpose of the card to individualize the fibres, would seem to be a ratio sufficient to have some effectiveness.

Starting now at the point where the cotton is caught on the cylinder, we notice that it is carried immediately in the opposite direction a short distance before it comes under the action of a number of flats that begin combing at F. Then from F, the cotton is carried forward while embedded in the cylinder-teeth from one flat to another until, at G, the action of the flats ends. Notice will have been taken of the close setting of the flats to the cylinder from Fig. 3, so close that any fibres placed between flats and cylinder must needs be torn apart or individualized by the action of so many teeth. After being carried by all the flats by the cylinder, the cotton continues a short distance farther to H, and then another smaller cylinder comes into operation, acting as a sort of "stock remover" to the large cylinder.

This smaller cylinder, which is placed almost up to tangency with the larger one, is called the doffer, and its only purpose here is to transfer the cotton from the main cylinder to this smaller one. The principle by which this transfer is accomplished is a trifle puzzling, as both the actions of surface-

speeds and combing are involved. The large cylinder turns at 160 revolutions per minute, or has a surface-speed of about 2,100 feet per minute; the doffer, 27 inches in diameter, moves about 10 to 12 turns a minute, or with a surface-speed of about 72 feet. This means that 29 inches of surface of the cylinder, all laden down with loosened fibres, pass by for every single inch of surface of the doffer, that moves away from the point of tangency. The inclination of the doffer cylinder-teeth being favorable to receive the fibres from the cylinder, and the distance between the two cylinders only 7-1000 of an inch, the transfer is readily effected so that the doffer practically backs off with the fibres that are thrown upon it, and moves away with them to the point J.

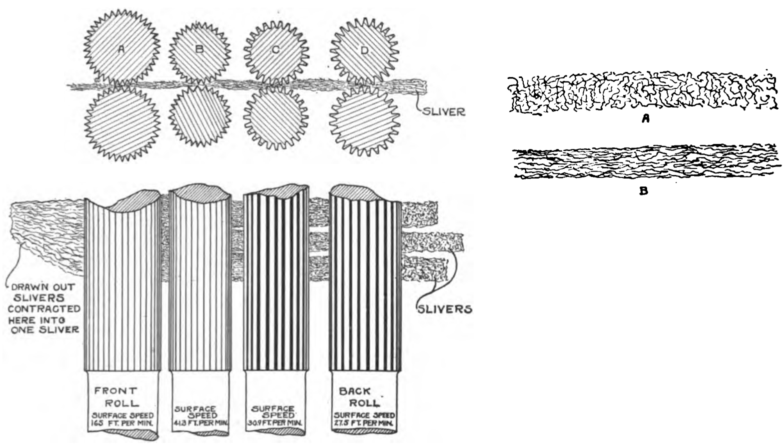
Here a vibrating comb acts to clear or knock the fibres off from the doffer in quick little raps, and they peel off in the shape of a broad transparent film of fibres. The film is drawn out a short length, when it is contracted into a funnel-shaped piece which brings the cotton to the form of a strand. Then, in the form of a strand, the cotton passes through some calender rolls to be slightly compressed, and into a coiler, where a means is provided to pack the strand away, in the shape of circles or coils in a can, for the temporary disposition of the fibres until withdrawn again later in the course of the manufacture.

### Drawing

In this process the cotton is received in the form of so-called sliver from the card, and, after having been operated upon, it leaves the process in much the same form in which it was received. Indeed, it does not appear from a casual inspection to have been changed at all by the action of drawing. If, however, several individual 1-yard lengths of the sliver were weighed, their respective weights might be say 55, 51, 59 and 51 grains each per yard, an average of 54, with a maximum variation of 5 grains from the average. Then at the end of the process, any other four yards, measured off at random, would likely have weights 40, 41, 42½, and 40½, an average of 41, with a variation of 1½ grains from the average.

The result of the drawing, and one of its main purposes here, has been to reduce the extent of the variations in weight,

it being immaterial, as will be seen later, whether the full weight of the sliver is 40 or 50 grains in itself. Beyond this added uniformity of the strand, there is another benefit derived in the operation of drawing, which might be termed the parallelization of the fibres. At the beginning of the process, the fibres of the strand from the card were crossed in every direction along its length, just as they were beaten off from the doffer cylinder by the vibrating comb. Now in drawing, these fibres become placed in very close alignment to one another, in fact an extreme case of the arrangement of the fibres would




DRAWING ROLLS

FIG. 4

be represented in Fig. 4, where A shows the crossed positions of the fibres, B the relation of the fibres after having passed through this operation of drawing. Three machines are required to bring about the required uniformity of the strand, and to parallelize the fibres, all of which are of the same type, the operations being merely repetitions of one another in different machines.

In Fig. 5 is shown an end sectional view of a draw-frame; also, in Fig. 4 on a larger scale, the four pairs of fluted rolls A, B, C, D. These latter are what do the drawing. The upper rolls move from contact with the under ones, while the latter are positively driven by gearing on their ends.

Six slivers from the card are passed in at A, and through accelerated surface-speeds of the rolls are delivered at D, in one combined sliver of about the same size as any one of the six to enter. There has, therefore, been a drawing action of six, to accomplish this reduction in size, and by so doing, thick variations in one strand will be found to have frequently come opposite thin variations of the other, while the resulting strand or sliver becomes more nearly an average of all.

At the front of the draw-frame an arrangement called a coiler is used, the same as that employed in connection with the card, and by means of it the sliver is packed away in a tin

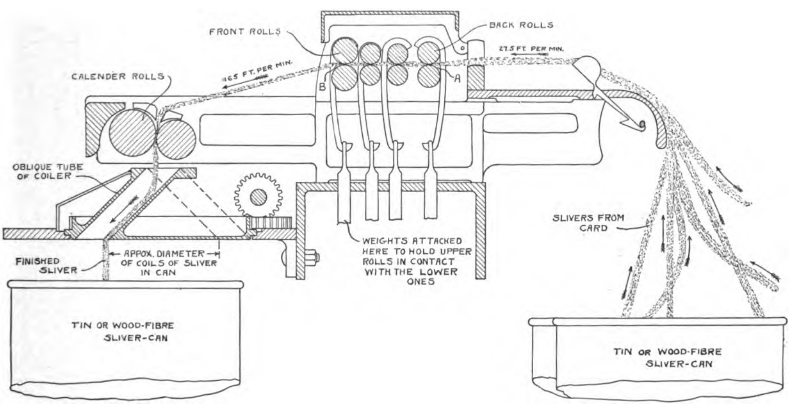



FIG. 5

can in the form of circles or coils, in such a manner that entangling is quite infrequent when it is withdrawn again for later use.

A delivery is the unit of capacity of the drawing-frame, and the term refers to the number of finished drawn slivers delivered from the front drawing-rolls in any complete drawing-frame machine. That is, when six cans of sliver from the carding process are clustered together at the back of the draw-frame, and their strands are all united and drawn into one at the front of the draw-frame, then this is called a delivery. Four, five, or even six finished drawn slivers are the usual deliveries constructed for draw-frame machines, depending upon

the space or special requirements of the room, where, in these cases, the cans at the back of the machines would be 24, 30, and 36 respectively in number.

## Flyer-Frames

A stage is reached with the completion of the carding process, and also in the drawing process, where the product from the machines is divided into many small lots, as was shown in those processes, in the use of tin cans as a means for the temporary storage of the cotton sliver. In the flyer-frame process, where the next manipulation takes place, these small lots are to be further subdivided, and one object of the present process is to arrange a more convenient shape for the cotton in its future handling than that of sliver in cans. The form assumed by the cotton for its storage in the flyer-frame, succeeding to that of sliver in cans, is called roving, and in this shape it is wound around wooden bobbins in many uniform layers like thread on a spool. That it may be more clear what this change is, it may be stated that there is a difference even between cotton sliver and cotton roving, though both may be of the same diameter and weigh the same; and this difference is in a twist which is added to the strand, being put in at the same time the roving is being wound on to the bobbins. Twist in connection with cotton-spinning is used for the purpose of giving strength to the strand, and it does so by producing a closer interlocking or cohesion between the individual fibres, while these in turn act to strengthen the strand as a whole. As applied to the cotton strand, the term "twist" denotes the number of complete turns or twists of the strand in an inch of length.

The three requirements, then, of this process are first, the reduction of the diameter, and this by means of the drawing-rolls; then the addition of a twist to the strand, by means of a mechanism called a flyer; and, lastly, the winding of the roving on a wooden bobbin, a convenient shape for the cotton in its subsequent handling.

In Fig. 6 an end view of three machines used in this process is shown, the first one being the slubber, which is fed with stock from the last drawing process; then the intermediate

frame, which is supplied with stock just made into bobbins on the slubber; and lastly the flyer-frame supplied with its stock from the intermediate frame. In each of these three machines the roving is drawn down to a diameter a little finer than the preceding one, while at the same time a slightly increasing number of turns of twist is put into the strand at each stage.

In building a roving bobbin the principal parts of the mechanism used in direct connection with the winding are the spindle, bobbin, flyer, presser, and drawing-rolls. Starting with the strand of sliver from a draw-frame in Fig. 6, it is first passed over the bar A, through the drawing-rolls B, then from C, after being attenuated, it passes to the top of a

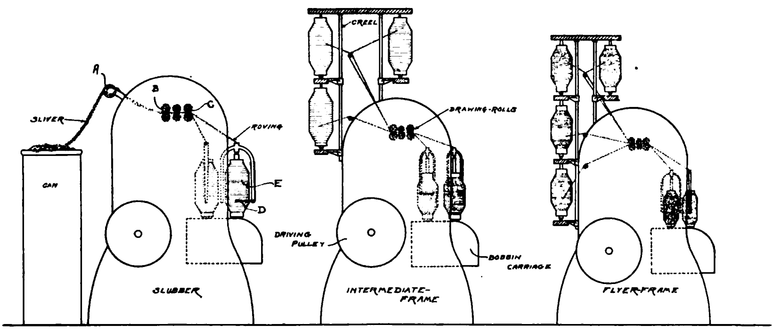
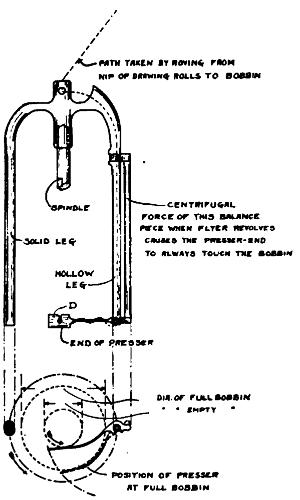



Fig. 6

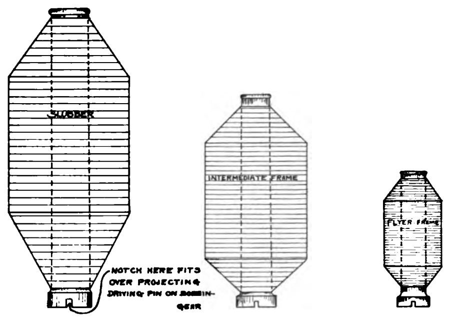
U-shaped piece called a flyer. One leg of this flyer is hollow, and the roving from the top is guided down within the leg to the metal arm D attached at right angles to the flyer-leg, which is called a presser. The roving, after passing down the hollow leg, is wound around the presser, and this in turn, as will be shown later, becomes the guide for the roving as it is wound on the wooden bobbin E. The other solid leg of the flyer is used merely as a balance to the hollow or working leg.

Consider for the moment the winding arrangement for the roving while just at the point of being put on the bobbin by the flyer and the presser. It is seen from Fig. 8 that the spindle A, upon which the flyer is pivoted and held fast, and also the gear upon which the wooden bobbin rests, held fixed to it by the projecting pin B, are both concentric. The end of the

presser attached to the flyer always presses against the surface of the bobbin, so that if the bobbin and the flyer were arranged with two separately driven trains of gears, and driven at the same speeds and in the same direction, the presser-end would under these conditions touch continuously the same spot on the bobbin during rotation. With the presser-end still touching the bobbin, but now, however, on one of greater size, while it still continues at the same number of revolutions per minute, its surface-speed at the end becomes increased, owing to the




FLYER




COMPARATIVE SIZES OF ROVING FRAME BOBBINS

| BOBBIN | A<br>DIA. OF BOBBIN INCHES | B<br>SPEED OF BOBBIN r. p. m. | C<br>SURFACE-SPEED OF BOBBIN ins.p.m. | D<br>SPEED OF FLYER & PRESSER r. p. m. | E<br>SURFACE-SPEED OF FLYER & PRESSER ins.p.m. | F<br>SURFACE-SPEED OF DRAWING ROLLS ins.p.m. |
|---|---|---|---|---|---|---|
| EMPTY | 2 | 491 | 3082 | 609 | 3828 | 746 |
| | 3 | 530 | 4994 | 609 | 5740 | 746 |
| | 4 | 550 | 6914 | 609 | 7660 | 746 |
| | 5 | 562 | 8824 | 609 | 9570 | 746 |
| FULL | 6 | 569 | 10734 | 609 | 11480 | 746 |

$C = A \times B \times \pi$
$E = A \times D \times \pi$
$F = E - C$

TABLE A

FIG. 7

point of contact between the bobbin and the end of presser being farther from the center of rotation. The rotation of the presser-end, D, while moving at a constant number of revolutions per minute, has, then, its surface-speed automatically increased as the bobbin fills, while the point of contact between bobbin surface and presser-end is pushed out farther from the center of rotation; so also is the bobbin's surface-speed increased the same amount, with the increase of diameter from the roving which is wound around it. In order for the presser-end to effect winding, or to lap the roving around the bobbin,

the surface-speed of the presser-end must always be a constant amount in excess of the surface-speed of the bobbin, to equal the amount of roving to be wound on or delivered from the drawing-rolls in a unit of time.

The means by which this adjustment of speeds between presser-end and bobbin is obtained will not be dealt with here, other than to say that it is accomplished with much accuracy through the use of an epicyclic train of gears and hyperbolic cone-drums. It is the principle of the winding just at the bobbin that is the important point to be gathered.

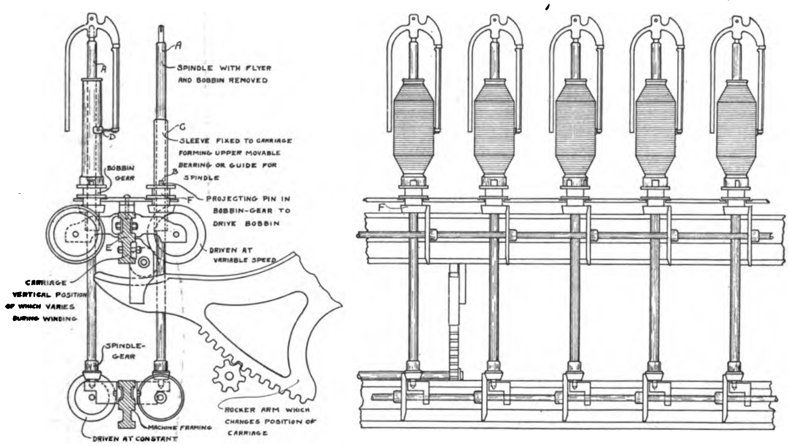



FIG. 8

In Table A, Fig. 7, the approximate figures are given for a slubber bobbin, five different diameters during the building having been selected.

As was stated before, on account of the number of small lots of cotton to be treated in exactly similar way, the machines or frames of the flyer-frame process are made to use the bobbin form of storage for the cotton, and now the machines are also made in multiples, as in the drawing process, where four to six deliveries were combined in a single machine.

In the roving frames, however, the multiplication is carried to a much greater extent, as the multiplication runs as high as from 40 to 200, of which each spindle represents a unit.

Much space is saved and convenience of operation and the avoidance of superfluous gearing are obtained by this arrangement, and a machine of the general type indicated in Figs. 6 and 8 is what is used.

In connection with the winding of the roving in uniform layers, it will be noticed in Fig. 8 that the vertical position of the spindle, flyer, and presser do not change, and also that between the spindle and the bobbin, there is a sleeve C fixed to the carriage E that forms the upper guide or bearing for the spindle. This sleeve, so-called C, enables the bobbin to

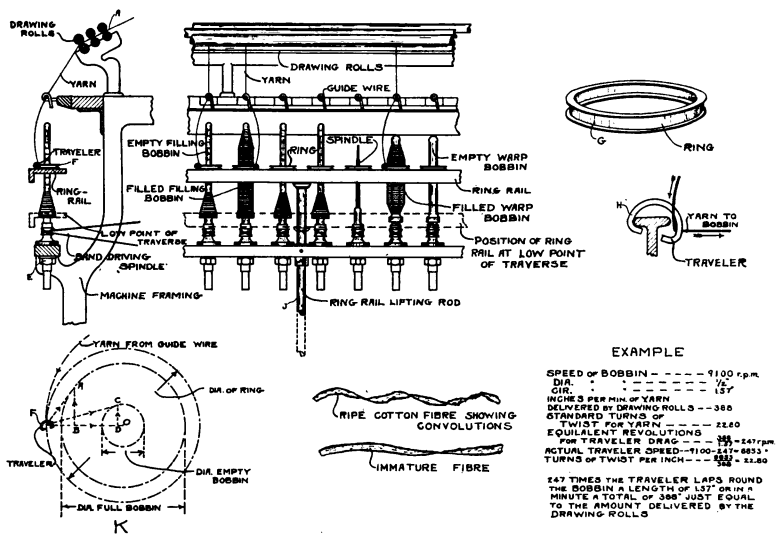



FIG. 9

slip up and down over the spindle without touching it, while the gear F, upon which the bobbin rests, and is driven, moves as a part of the carriage up and down during rotation. The carriage E, in passing through its traverse of 10 inches or more, carries with it the bobbins with all their adjacent gearing, and in so doing changes the point of guiding for the roving by the presser-end to the bobbin, so that it is laid on in uniform layers.

## SPINNING

The final operation which converts the cotton roving from the flyer-frame process into yarn is called spinning. This is

a process of drawing, combined with an operation that puts a large amount of twist into the strand during the time when winding on a wooden bobbin takes place. The drawing is required to reduce the cotton to the desired degree of fineness; the

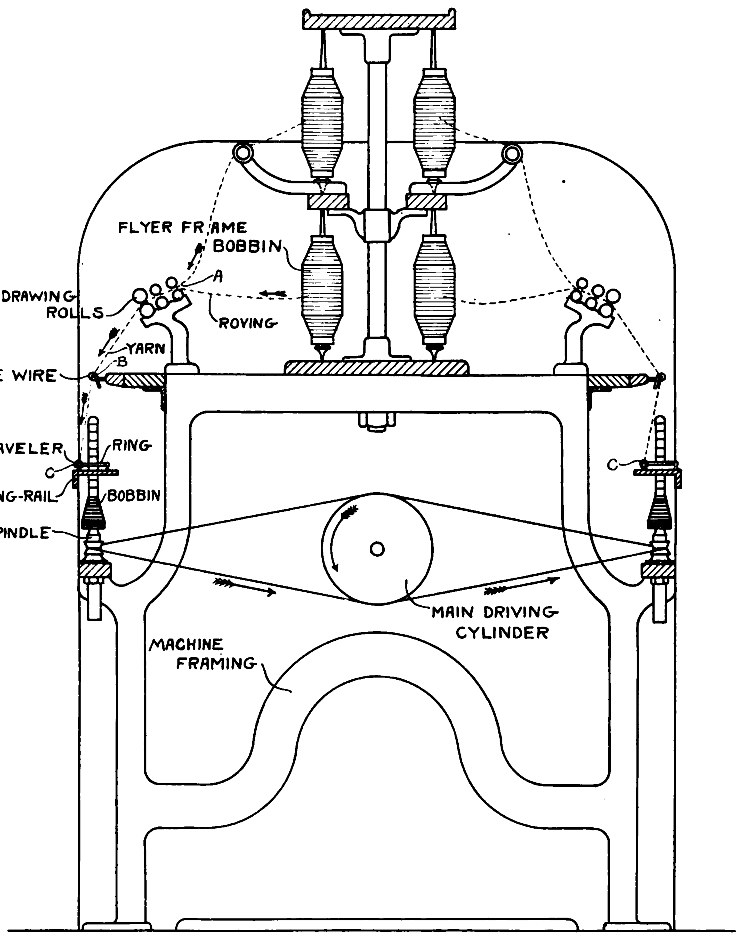



FIG. 10

twist is necessary to give the cotton some appreciable strength. The strand of cotton with this large amount of twist in it is called yarn, in distinction from a roving with its slight amount of twist, and though both might be of the same size

and weight per yard, they would be so designated. In size the spinning-bobbin is much smaller than the roving-bobbin, and yet the length of yarn on it is probably many times greater.

The single machine which is used to make this change in the condition of the cotton is called a spinning-frame, and its essential parts to be explained here are shown in Fig. 10. The first of these is the spindle, which is a rod of steel so fashioned, after many modifications leading up to its present form, that it is enabled to be revolved at the high speed of 10,000 revolutions per minute or more, on account largely of a self-contained and self-lubricating bearing. The spindle bearing is fixed in its position on the spinning-frame by the nut E (Fig. 9), and is exactly concentric with the ring F.

This ring is shown separately at G. It performs a most important part in the operation of spinning. Its section, it will be noticed, is nearly that of an I-beam, and over the upper flange during spinning a spring loop of wire, or a clip, called a traveler, is snapped, that it may run around freely thereon.

This traveler is again shown at H on an enlarged scale. While swinging around on the ring, it is the means of winding and twisting the yarn as it goes to the bobbin. The bottom flange of the ring is snapped in between little clamps attached to the ring-rail, so that the ring is held fast to it, and, as before, is exactly concentric with the spindle.

By means of a ring-rail lifting-rod J and a cam motion, the position of this rail, containing a number of rings varying from 75 to 150, is alternately changed slowly up and down, through a traverse of 6 or 7 inches.

Returning now to the operation of the stock through the machine, we shall see, as in the case of the intermediate and flyer-frames, that the cotton, while in process of treatment, was held on bobbins resting in racks or creels, and this is similarly the method used for holding the cotton in the spinning process. From the flyer-frame bobbin, then, which rests in the creel, or rack, of the spinning-frame, the cotton unwinds and is drawn in at the drawing-rolls A, Fig. 10. Accelerated surface-speeds of these rolls attenuate the roving to the required fineness of diameter, and then the strand passes from the rolls through the guide wire B to the metal clip or traveler C, then

finally is wound on the wooden bobbin. At the point where the cotton is twisted and in the action of being wound round the bobbin, after leaving the guide wire, the spinning-frame operation has its difficult part to see.

In Fig. 9, at K, on a larger scale, the winding and twisting arrangement is more clearly brought out. The winding operation, under certain special conditions, will show better the principle involved than under normal conditions of running.

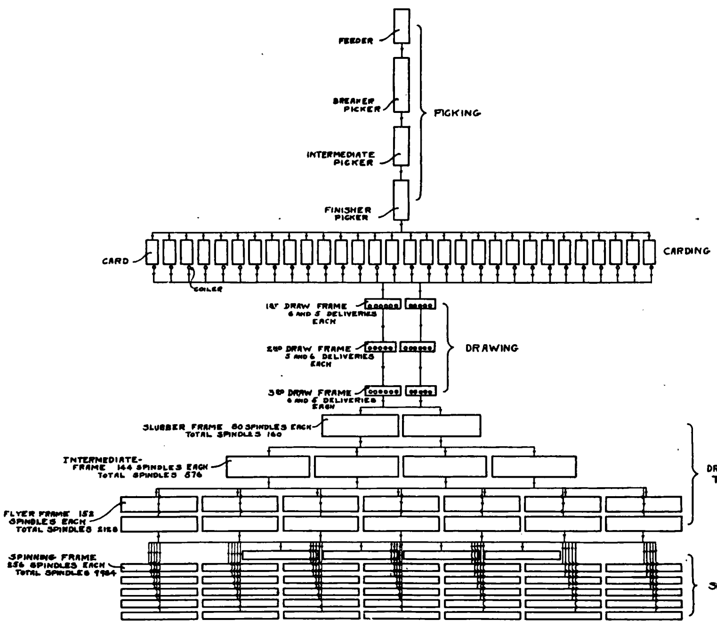



FIG. 11

Consider first the traveler to remain stationary on the ring; then the yarn fed through it to the bobbin would be wound on the bobbin at a rate equal to the surface-speed of the bobbin. This for a bare bobbin of the diameter of $\frac{1}{2}$ inch and a spindle-speed of 9,000 revolutions per minute would be nearly 14,150 inches in a minute. The drawing-rolls A deliver, however, only about 360 inches in that time, which it is proposed will be wound on the bobbin at the same time. The relation in speeds that meets this large difference in surface-speeds is

obtained by allowing the traveler partially to catch up with the spindle or bobbin rotation, by swinging round on the ring, meanwhile paying out yarn through the traveler to the bobbin.

Again take the case of operation, when the bobbin and traveler move at the same turns per minute, then there is no winding at all, and instead it is entirely twist that would be put into the yarn. Between these two extremes, a speed for the traveler is found that admits of the necessary winding action to take up the yarn delivered by the drawing-rolls, and the balance of the revolutions is utilized in putting twist into

SUMMARY OF OPERATIONS AND PRODUCTION OF MACHINES USED FOR 10000 SPINDLE MILL SPINNING Nº 30

| NAME OF MACHINE | CAPACITY IN LBS. PER 10 HOUR DAY | MACHINES REQUIRED ON BASIS OF 10000 SPI.D. NUMBER | NET PRODUCT IN LBS. AT END OF OPERATION | USUAL % WASTE TAKEN OUT | NAME GIVEN TO THE PRODUCT DELIVERED FROM MACHINE | WEIGHT OF COTTON PER YARD | TURNS OF TWIST PER INCH | NO. OF ENDS DOUBLED INTO ONE | DRAFT OR ATTENUATING ACTION OF MACHINE | SIZE OR HANK* OF COTTON |
|---|---|---|---|---|---|---|---|---|---|---|
| FEEDER | 4500 | 1 | 2623 | 3 | RAW COTTON | | — | — | — | — |
| BREAKER PICKER | 2500 | 1 | 2570 | 2 | LAP | 7000 GRS. OR 16 OZS. | — | — | 4. | .00119 |
| INTERMEDIATE PICKER | 2500 | 1 | 2516 | 2 | LAP | 7000 GRS. OR 16 OZS. | — | 4 | 4. | .00119 |
| FINISHER PICKER | 2500 | 1 | 2462 | 2 | LAP | 6120 GRS OR 14 OZS. | — | 4 | 4.50 | 00134 |
| CARD | 800 | 30 | 2354 | 4 | SLIVER | 54.1 GRS. | — | — | 115. | .154 |
| FIRST DRAW FRAME | 233 PER DELIVERY | 11 | 2300 | | SLIVER | 52.8 " | — | 6 | 6.16 | .158 |
| SECOND DRAW FRAME | 229 PER DELIVERY | 11 | 2300 | | SLIVER | 52.1 " | — | 6 | 6.08 | .160 |
| THIRD DRAW FRAME | 220 PER DELIVERY | 11 | 2300 | | SLIVER | 50.2 " | — | 6 | 6.23 | .166 |
| SLUBBER | 14.85 PER SPINDLE | 155 | 2300 | 2 | ROVING | 10.68 " | 1.06 | — | 4.70 | .78 |
| INTERMEDIATE FRAME | 3.92 PER SPINDLE | 586 | 2300 | | ROVING | 3.65 " | 1.82 | 2 | 5.90 | 2.30 |
| FLYER FRAME | 1.07 PER SPINDLE | 2150 | 2300 | | ROVING | 1.19 " | 3.17 | 2 | 6.08 | 7.00 |
| SPINNING FRAME | .23 PER SPINDLE | 10000 | 2300 | | YARN | .28 " | 26.01 | 2 | 8.57 | 30.00 |

* A HANK IS THE NUMBER OF 840 YD. LENGTHS IN ONE POUND — IF 840 YDS. THEN Nº 1, IF 7 X 840 YDS. THEN Nº 7

TABLE B

FIG. 12

the yarn. The selection of a properly weighted traveler gives this relation in speeds to a nicety, so that the traveler has just sufficient weight to cause it to drag on the ring an amount that would be equivalent in surface-speed to the length of yarn delivered from the drawing-rolls in a minute, while the rest of the speed goes into putting twist into the yarn.

The whole winding scheme by the traveler is virtually the same as the winding on a flyer-frame, except that in the latter case, the corresponding amount of lapping of the roving about the bobbin by the flyer, and the turns of twist put into the

roving, are determined mechanically and positively, while, in spinning, the winding and twist are automatically put in together by the traveler, and without that same precision.

Reference to Fig. 9 shows why it is that the traveler is forced to turn on the ring at all. The pull of the yarn at the bobbin during winding can be divided into two forces, one of which acts along line BD, and is ineffective except to pull the traveler towards the center O and thereby cause friction between the ring and the traveler. The other force AB (or CD when bobbin is empty) acts tangentially to the ring or bobbin, and is the one that really causes the rotation of the traveler on the ring.

Now, while the yarn is being fed through the traveler to the bobbin and swings round on the ring, the ring being fastened to the ring-rail, which moves up and down, causes the point where the yarn is guided to the bobbin by the traveler to change continually, and so the yarn is laid on in uniform layers.

Spinning-frames like roving-frames operate in multiple form; that is, a large number of lots of cotton are drawn, twisted, and wound on bobbins at the same time, to save the unnecessary duplicating of parts.

The foregoing explanation has embodied the essentials in the various processes of cotton-spinning of interest to the average reader, and a summary in diagram form, together with the numerical relations given in table B, shows additional points perhaps not appreciated before.

Fig. 11 indicates by the arrows the passage of the stock from one process and machine to another, on the basis of figures in Table B, and shows especially the increasing multiplication of the machines, necessary to take care of the product at each stage, as the capacity of each unit grows smaller. The figures, also, in Table B are applicable only to a mill running on yarn of a particular size, namely 30's, though the productions and particulars of a yarn of any other size would be similar in many respects.

## WORK OF A UNITED STATES DEPUTY SURVEYOR

BY LOUIS ROSS,
U. S. Deputy Surveyor
Harvard, A.B., '04. L. S. S., S.B., '05

### Introduction

More than 80 per cent of all the area of the United States was originally in the direct ownership of the Federal Government; some 40 per cent of this area is still under its control. This vast domain has been and is being disposed of, under the authority of Congress, in various ways, such as, for homesteads; stone, desert, mineral, grazing claims; subsidies to railroads, subsidies to schools; for reclamation, to be redistributed in smaller lots of irrigated farms; for Indian and military reservations; forest reserves; national parks, such as Yellowstone, General Grant, Yosemite; etc., etc. The disposition and administration of this great area requires a comprehensive and unified system of surveying, and is under the control of the United States General Land Office, which is a division of the Department of the Interior. Each state containing an appreciable amount of public land has a Surveyor-General, appointed by the President for four years. The Surveyor-General does no surveying, his duties being executive, — to let the contracts for surveys, receive the returns, have them platted, and to transmit the completed notes and plats to the Washington office and also to the local United States Land Office, where prospective settlers may consult them. The actual field work is done under mileage contract by a United States Deputy Surveyor.

### Importance

The system of United States land surveying is based on a few controlling, antiquated Congressional laws, and has been adapted and developed by many precedents, regulations, and customs to its present form. It has many characteristics that distinguish it from other classes of surveys such as railroad

location, irrigation, municipal surveying, characteristics that make it of peculiar importance to the public, and more so to the engineer. Some of the characteristics are:

1. It is the only system of surveying bearing the authority of Congress upon all its details.

2. Under its provisions nearly every acre of some 80 per cent of the area of the United States is surveyed, deeded, subdivided, and sold. As the center of population travels westward the time must surely come when "unappropriated land" will be as exotic an expression in Oklahoma as it is now in Massachusetts. Land divisions, disputes, and decisions will require closer and closer surveys, all dependent on the methods used in the original surveys. This system enters, therefore, more intimately than any other, into the interest of the agricultural and mining industries of the United States.

3. The geographic knowledge gained from these surveys, and presented by the United States General Land Office in its township and state maps is, for the present, the only authoritative information for many portions of the United States. It is useful to be able to find and interpret such information.

4. As a purely idealistic scheme of nomenclature it is as far above the old English method of metes and bounds as the alphabeto-numerical street designation of Washington, D.C., is to the cow-lane system of Boston. With the description SE$^4$SE$^4$S11T13SR6EMDM, designating a certain 40 acre tract in California, a perfect stranger can, with the aid of a few maps, buy a ticket in New York direct to the nearest railroad station, here hire a rig, and drive up to the tract with as much certainty as he would drive up to his country club, or to his favorite camp in the White Mountains, — and that without asking any questions.

5. Young engineers who enter the employ of the Federal Government, of any Western railroad, or who expect to have any dealings in reference to land matters in the West are sure to meet with problems, more or less intricate, with regard to United States Land surveys. Among the questions in surveying set in a United States Civil Service examination for engineers there was one covering the United States Land survey system. The announcement stated that this will be one of

the requirements. Out of some fifty candidates two or three answered the question correctly — these were Western engineers. Not a single candidate from the East showed any comprehension of the system.

To the deputy in the field it presents problems that do not usually occur in any other branch of surveying. His work is surveying plus; surveying plus mountaineering, surveying plus forestry, surveying plus prospecting, plus cooking, plus woodcraft, — one or the other of the pluses predominating, but always plus. His work is essentially that of the prospector, the explorer. He is the forerunner of population, of homesteads. When the demand for land in a given section begins to be felt, he is sent out to survey that section, after which legal entries may be made and patents or deeds for this land obtained, otherwise proprietorship is quite uncertain, since no legal boundaries for the subdivisions exist.

To quote an actual and typical example. A prospector some seventy years old came from Utah to Southern California in search of gold. Unable to find any, he selected a small oak flat in a rugged, uninhabited canyon, and there he settled. It was "unsurveyable" Government land. He hewed the native oaks, built his log cabin, cleared the land, dug irrigation ditches, cultivated the flat, and made it his home. Thirty years he lived there, alone, shunning population, a veritable hermit; his life's aim, the improvement and ownership of this flat. The law requires but five years of residence and cultivation, yet after thirty years of steady and beneficial cultivation the land was not his, because it was unsurveyed, on account of its extreme ruggedness. It fell to the writer's lot to survey this whole canyon. As the lines and corners reached this centenarian's claim his spirits and interest rose; with the one hundred years lightly borne on his shoulders, the old mountaineer rode out on horseback to where the section corner bounding his claim was being set, watched, and fairly played, happy as a boy with a new red wagon. For thirty years he waited this day, to see his claim bounded, to own legally the ground on which he spent so large a portion of his life's efforts. Without the survey he could not claim a square foot of ground.

Nearly all the land close to the railroads, towns, and principal highways has been taken up long ago. The unsurveyed portions are those least desirable because of their inaccessibility, ruggedness, climatic rigors, barrenness, etc. These are the deputy's fields of operation. On making inquiries from nearby inhabitants he is often told that no white man has ever been across those mountains, that no trail or "lead" or foothold has ever been found for crossing that canyon, that no beast or man can squeeze through that thick, high buckthorn. These mountains, canyons, and buckthorn flats are crossed by township or section lines. The deputy must find a way of overcoming them, or give up the work. On the completion of his work he knows more about the area he has covered than any other person. It is the pioneer exploration that gives zest and pleasure to the work.

The party the deputy has is usually small. Neither the price paid by the United States nor the field conditions permit the employ of more than two or three men besides himself. One experienced assistant and one helper are usually sufficient; for country covered with heavy undergrowth a third man, as axman, may be useful, — otherwise, as a roustabout, he is a luxury, and often an impediment. In this small party Democracy of the most exaggerated type reigns; specialization is useless, while a rounded knowledge of camp, forest, animals, books, men, instruments, — these are of the greatest value. Miles from settlements, the deputy who cannot cook will be controlled by his helper who can, as soon as that helper discovers that he is indispensable, and if he cannot saddle and pack a burro he will be controlled by the helper who can. To get the best work from his party he must be in appearance, as well as in fact, master of all details that enter into the work. He must know how to handle his burros as well as the handling of his transit; how to prepare a breakfast from half of nothing and make it taste well; how to take a Polaris observation, and how to crawl back afterward to camp through brush and over plateaus of broken boulders. "Camp" to the deputy means two blankets with hot coffee and beans, and if night overtakes him without his "camp" on the top of an inaccessible mountain, or in an impassable canyon, — "hung up on the bush," the

hunter calls it, — then he must know how to make himself and his men comfortable with a big camp fire and lots of good stories.

Again, one transitman makes a set-up in ten minutes and takes two hours to cross the canyon to the next ridge, while another transitman, being slow in figuring, takes thirty minutes to make a set-up and one hour to make the next ridge; then the second man may be a poorer transitman, but a better mile-maker, and the mileage counts. In general the time occupied in going from point to point is from one to four times as great as the time spent in actual trigonometric operations; the ability to get over the ground quickly is therefore a great element in the success of the work. "Stick to the ridges" may be the best rule for one district, "follow water" for the next, and "take south side of slopes" for the third. The formulation of such laws requires a deep study of topography; to pick up a deer trail, a vague scratch through the brush, and follow it up over broken rock and thicket requires an intentness and exercise of mind that compares well with that required in mathematics. The mountains are the masters, to fight them by brute force means failure, they must be respected, and means of overcoming must be adapted *to them.* The ability to overcome natural obstacles, not by lavishing one's energy but by self-adaptation and conservation of energy, — this is an art essential to this class of surveying.

Then again, the deputy's work, done under a contract basis of so much per mile, is avowedly a dollar-and-cents survey. Deep in his note book, together with data on climate and astronomy, he has tabulated the cost in cents per set-up, the cost of blazing through 100 feet of thick bushes, — yes, even the comparative cost of taking a sun or Polaris observation to determine the true north. The cost of surveying is, in general, as uncertain as the climate, and borne with the same sort of resignation. Surveys of magnitude are usually executed under the financially protecting wing of a municipality, state or federal government, or under that of a corporation to whom the survey represents but a small percentage of the total proposed outlay; the cost of the survey is therefore of secondary importance, — the engineer in charge being intent wholly on

obtaining the required data. Here the deputy must be able to estimate the cost of, say, a 100-mile-mountain survey, when he sends in his bid, within a very close margin, then he takes the field and must make good that estimate or stand the loss. Under such conditions he appreciates and measures the cost of each check-reading, each triangulation, each increase in accuracy, just as the earthwork contractor times and counts his fresnos scrapers, or dump cars.

## Requirements

The technical portion of the survey must be carried out in accordance with the United States Manual of Surveying Instructions prepared by the Commissioner of the General Land Office, and briefly referred to as "the manual." This is a book of some two hundred pages of print, with many plates and diagrams, advising, informing, and prescribing all the technical details of the work. This book becomes his surveying encyclopedia, his field bible, his "Guide to the Perplexed." Various portions of this manual, tables, diagrams, and complete chapters have been copied or rewritten into many text books on surveying. The engineer, interested in United States Land surveying, cannot do better than read through the original manual, rather than the excerpts that have been taken from it. The manual may be obtained from the United States Printing Office in Washington, D. C. The reader of the manual may find its phraseology somewhat stilting, jurisprudential; some of the technical portions savoring with the must of a hundred years, but it is quite complete and usually clear.

The demands generally made upon the deputy for a satisfactory survey may be analyzed in three parts:

1. *Lines.* Running a transit line along the bearing required by law; and marking the line by cutting out the underbrush along the line, or by blazing a sufficient number of trees on either side and close to the line, according to the nature of the vegetation. In barren country no physical mark of the line is left after the survey.

2. *Corners.* Setting legally authorized corners at each half mile of line approximately. These corners must be as

permanent as possible, their exact form being minutely and precisely prescribed by the manual.

3. *Notes.* The return of a neatly written set of notes describing all the field operations, the topography of the lines surveyed, the form and description of corners set, etc., etc. The form, phraseology, subject matter, even the abbreviations and punctuation of these notes is minutely and precisely prescribed by the manual.

The satisfactory completion of these three divisions of the work is the whole aim of the deputy. The subject will therefore be treated under these three heads. For a full exposition of the requirements the reader is referred to the manual; only the general principles will be taken up here.

## Foundation of System

The fundamental, though superficial, aspect of the system may be put as follows:

*(a)* Through an arbitrarily selected point a "Principal Meridian" is run north and south, and a "Principal Base Line" east and west, with corners set every half mile. This forms a system of coördinate axes. There are some thirty such independent systems in the United States, each usually referred to by some geographic name, as for instance "Mt. Diablo Meridian" in California, written MDM.

*(b)* Parallel to these two axes, and six miles apart, two other series of lines are run, with corners half a mile apart, thus forming six mile squares. Each square, containing approximately 36 square miles, or 23,040 acres, is a "township," written T or Tp. The lines bounding these townships are called "the exterior township lines" or briefly "exteriors." Every north-and-south strip, six miles wide, formed by these lines, is called a "range," written R, and is numbered with reference to the Principal meridian; thus, the 6th strip east of Mt. Diablo is called "Range 6 east, Mt. Diablo Meridian," written R6E MDM. Every east-and-west strip is called "a tier." Townships are designated by giving their tier and range numbers. Thus: T8S R6E MDM means: the 8th township south of, and in the 6th range east of Mt. Diablo. This township

therefore lies from 42 to 48 miles south, and from 30 to 36 miles east of Mt. Diablo. The coördinates, it will be noticed, are those of areas, not of points.

*(c)* Each township is subdivided into 36 sections of one square mile each. The north-and-south subdivision lines are called "meridionals," the east-and-west, "latitudinals"; corners are set on both sets of lines half a mile apart. The sections are legally designated by numbers beginning with 1 in the northeast corner of the township, increasing west and east alternately, until 36 is reached in the southeast corner of the township. This is as far as the United States generally subdivides the land.

*(d)* Each section, containing approximately 640 acres, is divided, by designation only, into halves, quarters, and quarter-quarters or "forties." The field surveys for these divisions of a section are made by private surveyors, their work being based wholly on the United States corners set around the section half a mile apart.

The 320 acres forming the east half of section 26 is written $E^2S26$, the exponent 2 stands for the denominator of $\frac{1}{2}$; likewise the southeast quarter of section 26 is written $SE^4S26$. $E^2NW^4S27$ T8N R6E MDM is read: the east half of the northwest quarter of section 27, in the 8th township north, and in the 6th range east of Mt. Diablo; being half of a quarter section, this designates an 80 acre tract. Likewise $NW^4SW^4S35$ T8S R6E MDM means: the northwest quarter of the southwest quarter of section 35, in the 8th township south and in the sixth range east of Mt. Diablo; being a quarter of a quarter, it designates a forty acre tract, or as it is popularly called "a forty."

This checkerboard system of one mile squares is what the early lawmakers intended to obtain; it is the popular, fundamental conception of the system. There are, however, three conflicting circumstances that quite prevent the realization of this ideal system. In the order of the magnitude of their effects they are:

1. The spherical nature of the earth's surface, since it is impossible to fit perfect squares on the surface of a sphere.

2. The allowable errors of closure of the survey under consideration.

3. The large, un-allowable errors in the old lines to which new surveys must be connected, due to faulty or fraudulent work, in those early surveys.

### Effect of Sphericity

In a six-mile square the two meridional boundaries converge forty (40) feet, *i.e.* the north boundary is 40 feet shorter than the south boundary; in a mile square the convergence is thirteen (13) inches; in a 24-mile square it is 640 feet, — the amount of linear convergence being approximately proportional to the enclosed area. Also a line started on a true east bearing, and prolonged as a true straight line, either by plunging or by reversing the transit telescope 180°, will form a tangent to the latitude circle at the starting point. In six miles this line will diverge 20 feet south from the starting point, and its direction will not be east, but four and a half (4½) minutes of arc south of east. In one mile the divergence will be six (6) inches in distance and 45 seconds of arc in bearing, — the linear divergence varying approximately with the square of the distance. These values are true, in round numbers, for latitude 40°, that of Philadelphia, Kansas City, Denver, San Francisco; they increase about one-third (1-3) at latitude 50°, near the Canadian border, and decrease about one-third (1-3) at latitude 30°, near the Mexican border. An exact analysis with formulæ for computing spherical divergence and convergence will be found in any good text book on geodesy. These round values are given to show the relative weight of this effect, and also to show that the effect increases rapidly with the sides of the square. To minimize the convergency effect it is best to employ small squares, which will be, of course, mutually disjointed, while to reduce the number of misjoints the larger the unit square the better. The square adopted as the unit of adjustment is a 24-mile square, that is, the boundaries of every 24-mile square run truly north and east; the east, west, and south boundaries are measured exactly 24 miles, the north boundary is less than 24 miles by the amount of convergence of the meridians. The 24-mile squares adjacent to the north and to the south do not, of course, join at the corners. Inside of these 24-mile squares the subdivisions are neither perfect squares

nor are they bounded by lines following the cardinal points of the compass. This 24-mile square is divided into four (4) strips by lines initiated on the south boundary six miles apart, and run due north, with corners half a mile apart, every sixth mile being a township corner. The width of the strip grows less by the convergency as it approaches the north boundary of the 24-mile square. The township corners are then joined in an east-and-west direction by lines run east random and corrected westerly, with corners half a mile apart, the total discrepancy due to convergence being thrown into the extreme west half mile. The principle of random lines will be explained in the next paragraph. The township is subdivided by running from its south boundary, a mile apart, meridional subdivision lines, not due north, but parallel to the east boundary of the township, which swings these meridionals 1 to 6 minutes of arc west of north, according to their latitude and their distance from the east township boundary. Corners are set half a mile apart, and every mile corner is connected to the one east or west of it by lines run east random corrected westerly. The convergency effect being of a theoretic and definite nature, is thus dealt with easily and, on the paper, with precision.

## Error of Closure

The allowable errors of closure are given by the manual in a rather complicated form, and the interested reader is referred to the manual for a precise statement. In general it may be said to be one part in a hundred and sixty (1:160). If the deputy's own work fails to close within this limit he must rerun his lines, if it does close within this limit he must not adjust the lines, but leave and record the actual, measured distances and bearings. The closure is always made by the north boundary of the square, which is run as a random-and-corrected line. Thus, suppose two parallel lines are started, just one mile apart, on a true parallel of latitude, and run one mile north each, with corners at the end of each mile, — then these two corners ought to be just one mile apart and lie due east and west of each other, and to locate a half-mile corner between them it is necessary to run only half a mile from one toward the other due east or west. As a matter of fact, this line will

neither measure exactly one mile, nor will its direction be east and west, because of the errors accumulated in running all the four boundaries. The deputy is therefore required to re-run this whole mile in a supposedly proper direction, which is the direction of the south boundary of the section. This trial line is called a " random " line. The allowable limit of error being 1:160, which is 50 links or 33 feet per mile, then if the terminal point of his north mile falls within 33 feet, in any direction, from the corner previously established while running the meridional boundary, the closure is satisfactory. He then computes the actual bearing and distance, and re-runs the line back on the new computed bearing, setting the half-mile corner on this corrected line, not half a mile away, but midway between the two-mile posts. As an illustration, suppose his random line shows that the mile is 5,310 feet long, and that its bearing is S89°47′E, instead of 5,280 feet east, he re-runs the line back on a bearing of N89°47′W, and sets the half-mile corner at 2,655 feet from either post. The corrected line is marked by blazing, the random is not marked. The square mile is then returned in the plats and recorded in all official dealings just as measured, not closed.

The random-and-corrected lines are thus the deputy's checks, by which he tests his work in the field. They are not parallels of latitude, being run as straight lines, not curves, and usually at an appreciable angle with a true east-and-west line. On the records they carry all the discrepancies due to convergency, poor alignment, poor measurement, made in the other boundaries. However, the very misclosure of the random line shows that the meridional boundary recorded as one mile N.0°2′W. is most likely neither a mile long nor is its bearing as recorded. The insignificance of the convergency effect may be appreciated by comparing the values given previously in this article with the 33 feet of allowable error per mile.

To the surveyor accustomed to work in populated districts this allowable error may seem great; usually, however, the ruggedness of the topography makes even this accuracy hard to attain. Also, the value of the land varies roughly from less than nothing to about $1.50 per acre, while that of the survey

is from 5 to 30 cents per acre, making the survey cost from 5 to 50 per cent of the land value. Any greater accuracy would increase the cost to a prohibitive point.

## Old Surveys

The details of United States Land surveying have been, and are gradually being, restricted and improved to accord with the growing value of the land. Many of the older surveys were made by the magnetic needle alone, and very crudely chained. A recorded mile may be in truth a mile and a half in length, and 10° away from its recorded bearing. A comparison of the notes of old surveys brings this strikingly to the eye. The older the survey, the more meager the notes. A set of notes of a survey made in 1854, lying before the writer now, illustrate the point. Mile upon mile of line has not a word of description, excepting the monotonous refrain at every half mile, "Set a post as instructed." Yet this land covers a most varied portion of Santa Barbara County in California, every 1,000 feet having a topographic variety that should have been described. Moreover, miles and miles of topography, neatly described and typewritten, may have no counterpart in the field, — the line, corners, topography having been manufactured from the warp and woof of a dishonest surveyor's brain. Legally established corners and lines cannot be changed. It has been ruled over and over again in judicial findings, as well as by Congressional laws, that corners are the true boundaries of land, that the recorded distance or bearing between corners is simply an aid to relocate the corners, in case they are lost. Now, the deputy is required to begin his survey from certain supposedly existing corners, carry through the survey on supposedly correct boundaries, and tie on to other supposedly existing corners. Arriving in the field he spends much time in finding a starting point, runs a large portion of his work, and just when he is ready to tie on his lines he finds errors of half a mile, or even of a whole mile in a recorded mile, posts missing, or the whole survey a fraud. He is required to locate those errors, and tie on his survey to the old lines. This is one of the most vexatious

questions he has to deal with, — its solutions are as varied as the sources of trouble and cannot be taken up here; the interested reader being again referred to the manual.

## Other Prescriptions

"All lines shall be plainly marked on trees, and measured with chains, containing two perches of 16½ feet each, subdivided into 25 equal links." Distances must be measured in chains and links, the use of feet or inches, or of an engineer's tape, being prohibited; but heights and diameters of trees must be measured in feet and inches. Thus a ridge must be 5 *chains distant* and 200 *feet high*, a tree must be 40 *links distant* and 30 *inches in diameter*. The deputy must survey the land in person, he himself must act as "compassman," the employ of a "compassman" being expressly prohibited. The use of a compass is also expressly prohibited for line running. "Only a transit of approved construction or Burt's solar compass" may be used. If no solar attachment is used, "Polaris observations every clear night will be necessary."

Ten square chains (not ten chains square) make one acre, and eighty chains make a mile. These relations make the chain system much more convenient than the foot system in measurements of acreage.

*Notes vs. Fact.* This covers the legal requirements of running the lines and represents *how the notes are written up*. How the actual field work is done — that is a different story. The situation is like this. The deputy is sent out to survey a certain area; the manual, which represents his employer, the United States, tells him *how* to do it. He completes the work and returns; unless he tells that he did the work according to the manual, his work will not be accepted. He must tell the story as the manual orders. The notes are therefore always right, the closures excellent. In the field, however, he is forced to adopt methods and instruments less ancient, even though the bidding of the manual has to be stretched tight to cover such a procedure.

Starting with the best of intentions to run a true line N.0°3′W., the deputy finds at the very start his vision is

obstructed by a tree. He offsets laboriously by a 90° offset, occupying the best part of the forenoon and losing several minutes of arc in the accuracy of his azimuth, so carefully determined from Polaris after a night of hardship. No sooner does he regain his line than he finds another tree or cliff facing him; he offsets that too, and finds more obstacles, more jungle growths. After a while it dawns upon him that the whole line is a series of offsets, that he cannot run N.0°3′W. Yet there is the manual that prescribes how to run the line, and in his notes he must say, "Thence I run N.0°3′W.," etc.

He goes on and finds his way stopped by canyons and saw-toothed ridges that defy ascent; his chainmen with the "chain containing two perches of sixteen and one-half feet each," standing before the gigantic canyons and broken cliffs, appear about as two men come with dippers in their hands to measure the flow of the East River. Chainmen who *can* chain this canyon would wear wings; those who *will,* straightjackets, yet, there is the manual.

The deputy finds the Western nights so clear that were he disposed to accept the invitation to observe Polaris every clear night, then he would spend the greater part of his nights on the mountain tops and in the canyon recesses, but the call of food and blankets, beckoning to camp, is insistent, imperative, yet — the manual. He goes on and finds his way stopped by waterfalls, sheer cliffs. Across them and the next crest is the position of an important township corner which he must make or else drop the work. He looks at the cliffs, thinks of the corner he must set, — and forgets a dead man's rules made for generations long dead; he combines his God-given sense with his school-given trigonometry, and just *gets* across, — be it by feet, chains, or metres, sun or star, stadia or triangle, — only satisfied that the corner is in the right place, and well set. The notes show a bland remark: "Canyon, 3.46 chs. wide, course N.70°E." Some of the prescribed details, if carried out literally, would appear more like a fanatical religious ordeal than modern surveying.

The mile between sections 16 and 21, the notes state, has been run east random and corrected westerly. As explained previously the random is run to find the actual length and

bearing of the line, so as to be able to locate the midway point. In a state of nature this line exists physically only as a post, set midway between two other posts. The layman does not see why "east random corrected westerly" is satisfactory, while running the same line in the opposite direction would vitiate the survey, nor does the deputy see the reason; he does, however, know, being on the ground, which direction is the most practicable, most convenient, quickest, and follows his judgment, — but in the notes he "runs east random, corrected westerly."

The writer has spent two weeks in the field trying to reconcile a set of old notes with actual conditions on the ground, and to locate a discrepancy of over a quarter of a mile between his measurements and those of the old survey on which he was to tie his lines. The old survey was a real one, this was evidenced by old blazes found along the line; the ground was impassable. How were the measurements made? The real answer would be to the credit of that surveyor's endurance, strength, and boldness, but the notes described a way that was absolutely impossible in the face of the existing topography — the form of the notes was in accordance with the manual. Unfortunately, in converting his real procedure into the fictitious one described, an error of nearly a quarter of a mile in a measured three-quarters of a mile crept in. This error developed errors of more than half a mile in the adjacent 2 miles. *The notes were correct.*

## Actual Field Processes

The actual field process of line running depends on the personal equation of the deputy.

One of the best methods is to run a traverse by stadia, as close to the required line as the topography permits. At each set-up the distance along the required line, and the deviation right or left, is computed. This locates the true line for the purpose of marking. The tape is used wherever the ground permits it, both to satisfy requirements and to check the stadia work. The corners are set at the coördinates computed from the required distance and bearing. The azimuth is carried by back sights, checked at every set-up by the needle, twice a day by the sun, and by the star when possible. The stadia is gradu-

ated to links and tenths of a link, both to satisfy requirements as well as for convenience, the chain system being particularly adapted to measurements involving square miles and acres. In clear country and for long sights, flags are used for backsights, saving the employ of a back rodman, and increasing the accuracy of the angular work. In obstructed country, with short sights, a back rodman is essential.

The procedure of the work is:

1. A true azimuth is determined by astronomic observations at the starting point, and the transit is oriented along the required bearing.

2. The front rodman is sent ahead to find a suitable point at a suitable distance, and *on line*. The points are usually the crests of ridges crossing the line, and the distance from 1 to 20 chains. A good rodman will line himself in within 3 degrees of the required line, his linear deviation being equal to the sine of this angle, roughly 1-20 of the distance; with a hand compass fitted with sights his deviation should not exceed 1½ degrees.

3. The transitman then tries to line in the rodman on exactly the proper course. This may be possible at times, usually it is not, because of obstructions between them or ahead. Readings are then taken, from which the distance and deviation right or left of the point set by the rodman is computed. At the next set-up the transitman tries to line in the rodman so as to deviate him in the reverse direction an equivalent amount, or at least as close to the true line as possible. The whole line run is, therefore, a zigzag traverse, crossing and rerossing the required line. With a good rodman very little lining in is necessary, and the deviations will be very small, sometimes as low as one or two links either side. In fact, the front rodman practically determines the speed of the work, and in a large way its quality. He should, therefore, be familiar with transit work, in order to appreciate more fully the desiderata.

4. The topography between stations is given by the front rodman, who holds the rod at each topographic feature as he passes over the line. In the majority of cases, however, a straight line joining the two stations is quite impassable. The

topographic feature is then located by one or another trigonometric operation that the ingenuity of the deputy may suggest.

5. When the point for a corner is approached the front rodman is lined in by the transitman, in line and distance, according to the computed coördinates, a mark is left there, and the rodman goes ahead to select a new point for a set-up. The transitman does not necessarily set up over the point where the corner falls.

Under favorable conditions stadia work will give an accuracy of 1:500; under very poor conditions, 1:100, and even as low as 1:50 for a single observation; 1:300 should be easily obtained, which brings this method within the allowable error.

Another method used is triangulation. The prominent topographic points of the area are located by triangulation, and the corners are " shot in " from the nearest triangulated points, and the lines are afterward marked. Two bases are measured with an accuracy of about 1:5,000 to 1:10,000, one at the beginning of the system, the other at the end as a check base. With any reasonable care this method will yield an accuracy far ahead of that given by stadia, taping, or chaining. By this method the deputy virtually does the work twice, once accurately, to satisfy himself, and again less accurately, running along the required lines, to satisfy requirements.

A still different method is to take angles from various points along the measured lines to other flags set on prominent points. This forms a set of triangles based on the linear measurements taken along the required lines, thus checking those lines.

## Corners

"After true coursing and most exact measurements the establishment of the corners is the consummation of the field work. Therefore, if the corners be not perpetuated in a permanent and workmanlike manner, the principal object of the surveying operations will not have been attained." A good corner is one that can be found easily, one that shows clearly by markings what lines it is intended to mark, and one that is permanent. The prescribed corners consist, in every case, of a corner proper, which is a small object defining the exact location of the point

and an accessory, which is a larger object, as a witness, some distance away, to enable the corner proper to be located and re-located in case it is lost. Eight types of corners are authorized by the manual, varying according to the nature of the country. In wooded country, a tree or a post with bearing trees are used; in rocky country, a stone or boulder with a mound of rocks or with bearing rocks are used, and where neither is found, then mounds of earth with charred stakes and pits are used. The size, manner of setting, inscription and description of these eight types are minutely prescribed by the manual. In each case the object is to secure the clearest and most permanent corner. A description of several types of corners is given in the sample page of notes in this article.

The setting of corners plays a large and important part in the deputy's work. The time occupied in setting one corner may be from 25 per cent to 100 per cent of the time occupied in running a mile of line; and the manner of setting one or two corners is a fair criterion of the quality of the work in running the lines. Though eight different types of corners are offered for a choice, yet the deputy is often at his wit's ends to devise a corner that will suit the location. Thus the point may fall on a broad mountain mesa of disintegrated boulders. To set a marked stone would be like setting a 2-inch pebble on a pebbly ocean beach. Legally a 20-inch stone, with a 2-foot mound of rocks is satisfactory; but being on the ground the deputy sees the uselessness of such a corner, — he knows that nothing short of a 50-foot hillock of rocks could be made findable. The position for the corner may fall on a steep slope, along the side of a sheer bluff, in unsteady soil, or in an otherwise unsafe or inaccessible location. In that case the deputy sets a witness corner at the nearest suitable place along the surveyed line. In one survey the writer was compelled to set more than half of all the corners as witness corners, which indicates the ruggedness of the country. The distance of the witness from its true position is recorded in the notes, but is not marked on the corner. Such a corner does not, therefore, inform the finder where its location is, without the original notes.

## Old Corners

In every survey the deputy is required to commence at and to tie his lines to the corners of the older survey, and he is furnished with the original notes of those older surveys covering the adjacent territory. The finding of these old corners is an art, — it requires all the intuition, woodcraft, and local knowledge that the deputy can command. In the unsettled locations where these surveys usually come there are few or none who know the location of these corners. All that the deputy has to guide him are the notes. The corners described in the notes may exist as described, may exist but be far off the mark, or may not exist at all, according to the quality and reality of the old surveys, and the kindness of the elements. As explained previously, the older the original survey the more meager the notes, the more doubtful the accuracy of the work, the more chance for those corners to have become obliterated.

Before starting on a "hunt" for a particular corner the deputy must size up the situation from all sides. Do the original notes look real or fictitious? What type of corner is it? How old is it? Are there any topographic features that will help locate it? If it is a "Post as instructed" set fifty years ago, without any topography half a mile either side of it, then the search is sure to be a failure. The lack of topography fails to limit its location; if set, the post will surely have rotted beyond recognition, while the absence of accessories prevents its relocation. Again, a tree corner with four bearing trees, set some thirty years ago, with a creek 5 chains to one side, and a trail 3 chains on the other crossing the creek at, say, 7 chains on a recorded bearing, — this corner should be found by any tyro, since the intersection of the trail with the creek locates the point in latitude and in departure, while of the five trees recorded at least a few will be found after thirty years; if a forest fire burned the trees, then their stumps will easily be found. These two illustrations of old corners are extremes; in general a critical inspection of the notes and the ground will tell the deputy what corner is likely to be found. The facts to bear in mind are: redwood posts, 4 inches in diameter, set as corners, will last ten to twenty years in good condition, and will be

recognizable for thirty years, posts of soft wood much less; in searching for trees allow for the increase in diameter; chop in a similar tree in the neighborhood, measure the number of rings per inch, and figure the increase in the diameter of the tree you search; the inscription may be completely overgrown with new bark, if so a half-raw junction or slit will tell the tale, and by carefully removing the bark the "image" of the lettering will be found on the inner face of the bark; to tell the age of an old blaze, cut in carefully at the blaze and count the number of overgrown rings that do not make a complete lap, this will often locate the old line; an old mound of rocks will seldom stay as a mound, look for a few stones together, then study their mechanical arrangement, to see if nature threw them together or whether they were hand-placed. If hand-placed, the problem is solved. Lines are usually prolonged from ridge to ridge; watch the ridges for little mounds of rock where the original flag and compass were set up; watch for blazes on the trees, and for cuts through the brush. The finding of a single stump, only 5 inches in diameter, cut some fifteen years ago on the top of a high, inaccessible mountain among virgin vegetation, has been, in the writer's experience, the means of locating another corner, without which the whole of the present survey could not have been closed.

After the first disconnected corner is found, additional corners are more easily located. In passable country these may be found by double pacing, and lining in with a Brunton, or folding-sight, pocket compass. Two men are needed for this. The deputy lines in his assistant, who counts his paces as he walks away from the deputy, going as far as the obstacles to vision will permit. There the assistant stops, and the deputy paces up to him, and lines in the assistant again, etc., continuing this until each comes to what he considers to be half a mile. Each keeps a separate tally of the distance, with allowance for broken topography. Over fair ground 25 paces are usually allowed to the chain. With two fair pacers it is seldom that their mean point will miss the true point by more than half a chain in half a mile, in distance or alignment; that is, the accuracy of the mean pacing would be 1:80 in distance or deviation, nor will they differ by much more than that between

themselves. At this point a search for the corner is begun, and if the corner exists it will be found in a few minutes. If the ground is impassable, then the slower process of transit and stadia must be resorted to.

## Notes

The entries in the field are made "in the deputy's pocket note books called tablets," from which "the original field notes are to be written out in ink, for the permanent record of the work. In these notes the deputy will make a faithful, distinct, and minute record of everything done and observed by himself and his assistants." The notes must show all the topographic and cultural features crossed by the line or near to the line, a description of all corners, and all the details of the method of work. A set of specimen field notes are appended to the manual, "indicating not only the method by which the deputy's work will be conducted, but also the form, order, language, etc., in which his field notes will be prepared . . . any departure from their details will be regarded as a violation of his contract and oath." A list of authorized abbreviations is given in the manual, "no others should be introduced. The arrangement of lines, blanks, spaces, numbers, and the general form of the specimen notes should be observed."

The form of the actual field notes is an individual matter with each deputy, depending on his taste and method of work. The returns, which are the re-written notes, called "the original field notes," are made up after the return from the field; they are now-a-days typewritten, instead of "written out in ink." The clearness and simplicity of their form speaks for itself. A sample page follows:

*Chains* *Subdivisions of T. 15 N., R. 20 E.*

45.50 Creek 8 lks. wide, pure water, course N. 60° E.; enter meadow land.

60.00 Leave meadow land, bears E. and W.

80.00 Deposit a quart of charcoal 12 ins. in the ground, for cor. of secs. 10, 11, 14, and 15; dig pits, 18 x 18 x 12 ins., in each sec., 4 ft. dist.; and raise a mound of earth, 4 ft. base, 2 ft. high, over deposit. In SE. pit

drive a cedar stake, 2 ft. long, 2 ins. sq., 12 ins. in the ground, marked

T15NS11 on NE.,
R20ES14 on SE.,
S15 on SW., and
S28 on NW. face, with 4 notches on S. and 2 on E edges.

Land, level.
Soil, rich loam; 4th rate.
No timber.

N. 0° 2′ W., bet. secs. 10 and 11.
Over gradually ascending ground.

28.00 Ravine, 18 ft. deep, course S. 30° E.
30.50 Begin ascent over stony ground, bears E. and W.
40.00 Set a granite stone, 16 x 6 x 6 ins., 11ins. in the ground, for ¼ sec. cor. marked ¼ on W. face; and raise a mound of stone 2 ft. base, 1½ ft. high, W. of cor. Pits impracticable.
43.50 Top of sharp rocky ridge, 20 ft. above the ¼ sec. cor., bears N. 75°E. and S. 75° W.
44.50 Begin descent.
48.50 Foot of descent, 25 ft. below top of ridge, bears E. and W., thence ascend along SE. slope of spur.
51.30 Johnson's barn bears N.62°30′E., about 8 chs. dist.
60.00 A point, 200 ft. above ¼ sec. cor., thence descend into ravine 150 ft. deep, course S.35°E.; ascend very steep slope to
80.00 Set a locust post, 3 ft. long, 4 ins. sq., 24 ins. in the ground, for cor. of secs. 2, 3, 10, and 11, marked

T15NS12 on NE.,
R20ES11 on SE.,
S10 on SW., and
S3 on NW. face, with 5 notches on S., and 2 on E. edges; from which

An oak, 12 ins. diam., bears N. 22° E., 17 lks. dist., marked
T15NR20ES2BT.

A pine, 14 ins. diam., bears S.65½E., 21 lks. dist., marked
T15N R20E S11 BT.
A pine, 15 ins. diam., bears S.41½°W., 27 lks. dist., marked
T15N R20E S10 BT.
An oak, 14 ins. diam., bears N.48¼°W., 23 lks. dist., marked
T15N R20E S3 BT.
This cor. stands on a SE. spur of Raymond Ridge, 560 ft. above cor. of secs. 10, 11, 14, and 15.
Land, mountainous.
Soil, stony, 5th rate.
Timber, oak and pine.
Mountainous or heavily timbered land, 59.60 chs.

S.89°49′E., on a random line bet. secs. 2 and 11.
40.00 Set temp. ¼ sec. cor.
80.17 Intersect N. and S. line, 23 lks. S. of the cor. of secs. 1, 2, 11, and 12.
Thence I run
N.89°59′W. on a true line bet. secs. 2 and 11.
Over rolling land.
19.90 Creek, 4 lks. wide, course S.60°E.
40.08½ Top of spur, 80 ft. above sec. cor.
Set a cedar post, 3 ft. long, 3 ins. sq., 24 ins. in the ground, for ¼ sec. cor., marked . . ., etc., etc.

## Formal Completion

With the "original field notes" the deputy returns a neat topographic map of the area surveyed, drawn to a scale of 2 inches to the mile. It will be noticed that the survey and notes cover only the sides of each square mile, not the interior area. Therefore a draftsman in the office would have to do a lot of guessing in order to connect the fragmental pieces of topography, taken along the borders, so as to make a correct topographic map from the notes. The deputy himself, in making up this map, guesses at the exact location of creeks, mountains, flats inside the section; his knowledge, however, is based

on personal observation and on such interior points as he might have located incidentally. Therefore, while the topography, as plotted along the boundaries, is accurate, the interior topography is not necessarily so. When the plats are made wholly in the office of the surveyor-general, without the deputy's aid, they are often quite misleading.

The notes and map, called "the returns," are then filed with the surveyor-general, with an oath as to their reliability, and with oaths from each of the assistants. The notes are examined in the surveyor-general's office. If the procedure of the work, *as described,* does not accord with the requirements, the deputy must return to the field and correct it; if the notes are not in the required form, he must re-write them; if both are satisfactory, then a preliminary map is made from them for the use of the examiner. The field examiner, or inspector, is a salaried employee of the United States Land Office; he is required to re-run 10 per cent of the deputy's work, also in strict accordance with the manual, and then he reports on the accuracy of the deputy's work. According to his report the survey is rejected, ordered to be corrected, or accepted. This step, the process of acceptance, takes from six months to more than six years, according to the complications of the case.

If the survey is accepted, then it is platted again and forwarded to the Washington office for a complete re-examination, to protect the United States against collusion. If the Washington office finally approves the survey and plat, then it is returned to the surveyor-general's office, where three copies of the plat are drawn, by hand, usually colored. The blueprint process has not yet come into use. One copy of the notes and plat is kept at the office of the surveyor-general, one is forwarded to the local United States Land Office, where prospective settlers may consult it, and the third copy is filed with the United States General Land Office in Washington.

After the acceptance and platting, the accounts of the survey are approved, the payment of which completes the contract of the United States Deputy Surveyor.

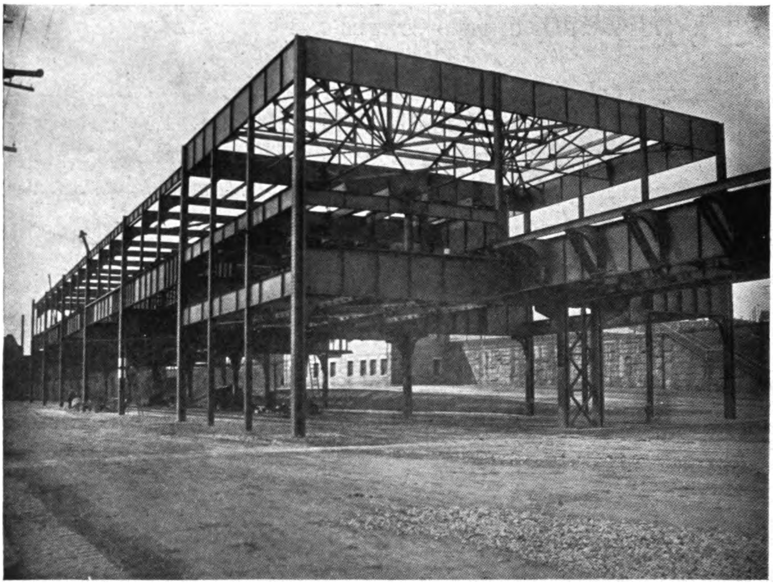


**Fig. 2**

STEEL WORK OF STATION BEFORE CONCRETED

**Fig 3**

STEEL WORK OF ARBORWAY, WITH FINISHED COLUMN

## FOREST HILLS TERMINAL OF THE BOSTON ELEVATED RAILWAY

BY JOHN WARE, S.B., '99

During the past summer the Boston Elevated Railway has constructed a station at Forest Hills Square, the terminus of the Forest Hills Extension. This last consists of an elevated structure running from the present terminal at Dudley Street, along Washington Street to Forest Hills Square, crossing the arborway of the Metropolitan Park System just north of the square.

The N. Y., N. H. & H. R. R., which parallels the elevated at this point, crosses the arborway with a stone arch bridge of five spans — three long ones over the roadways and two shorter ones over the bridle path and walk.

In order to harmonize with this bridge and to avoid noise, it was decided to cover the structure, crossing the arborway, with concrete, and thereby obtain an artistic result which is very desirable over a purely pleasure drive. The station itself comes in Forest Hills Square directly south of the arborway, and is of similar construction.

The type of structure, as far as the arborway, is merely steel columns on each side of the street at the curb, supporting transverse girders. These, in turn, carry longitudinal girders for the tracks. The bent on the north side of the arborway, however, is different, a double column being placed at the center of the tracks, as well as those at the curbs.

From this bent to the north face of the station there are six columns on the center line of the structure. Each one of these consists of four separate columns latticed together and spaced six (6) feet center to center transversely, and three (3) feet center to center longitudinally. These support two transverse girders which, in turn, carry four longitudinal girders on which the track floor is laid. On the sides of the outside girders there are brackets to take care of sidewalks. There are seven spans

of this type of structure alternating forty-five (45) and sixty-four (64) feet to the span according to whether it be roadway, footwalk, or bridlepath that is spanned.

The station consists of seven spans of fifty-one (51) feet each, a platform is on each side of the track, the inbound plat-

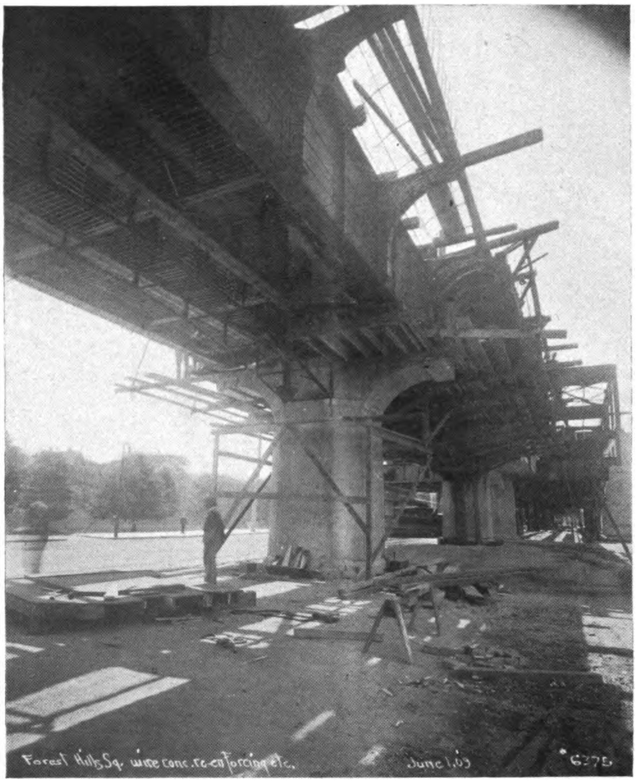



FIG. 4

FORM FOR ONE SPAN OF ARBORWAY IN PLACE, FORM FOR NEXT BEING SET

form being wider than the outbound. The transverse girders of the station are supported each on three columns, one on each side of the station and the other under the center of elevated tracks. The west column is on the curb line of the street and the others in the square. The north end of the station is roofed over for one span, containing the waiting and toilet rooms and

the employees' quarters, while for the remainder of the station the platforms are closed at the back and roofed over, being open toward the train pit, which is uncovered. The columns of the outside wall of the station extend above the roof, and are covered with concrete. Between them, the space above the platform level is filled in with woodwork which is covered with copper. Most of this space, however, is occupied by windows.

In order not to overload the structure with dead weight, it was decided to place the concrete with which the station and arborway was covered in thin walls of from three to five inches thickness, hollow spaces being left inside the structure. The columns, however, are solid and help to stiffen the structure.

In the arborway the columns are octagonal about 10 feet in diameter, as high as the under side of the transverse girders. The spans between columns are a combination of two kinds of arches: first there is an arch rib 4 feet 6 inches wide, on the center line of structure from one column to the other, then a flat arch extending in width from this center rib to the outside longitudinal girder and in length the whole of the span. From the outer edge of the flat arch a curved surface is carried up on the line of the brackets to the level of the track floor, and there the whole width is covered with an 8-inch slab of reinforced concrete to carry the track. On top of the wire ducts, which are on either side of the tracks, there is a sidewalk three (3) feet wide with a parapet wall of concrete.

In the station each of the side columns is covered with concrete to make a pilaster about three (3) feet thick and eight (8) feet long. At each end, however, the side spans are made solid with three arched openings on the ground level. The pilasters go above the roof, and are topped with an ornamental cap; the two end ones on each side being carried higher than the others, and made six (6) feet square with a different style of finish at the top. The wall girders, supporting the platforms between the columns, are covered with a hollow concrete arch, which gives the station the effect of a concrete structure as high as the platform level. The ends are finished in similar fashion, the north end having curved, while the south end has flat arches from each side to center post.

The structure as far as the arborway was completed in 1907, but owing to failure to get the station plans approved by the Railroad Commission, it was not possible to build the station until recently. The foundations were placed in 1908, and work on the structure of the arborway and the station in the square was started last spring.

The first work undertaken was that on the big columns in the arborway. These were built one at a time to the under

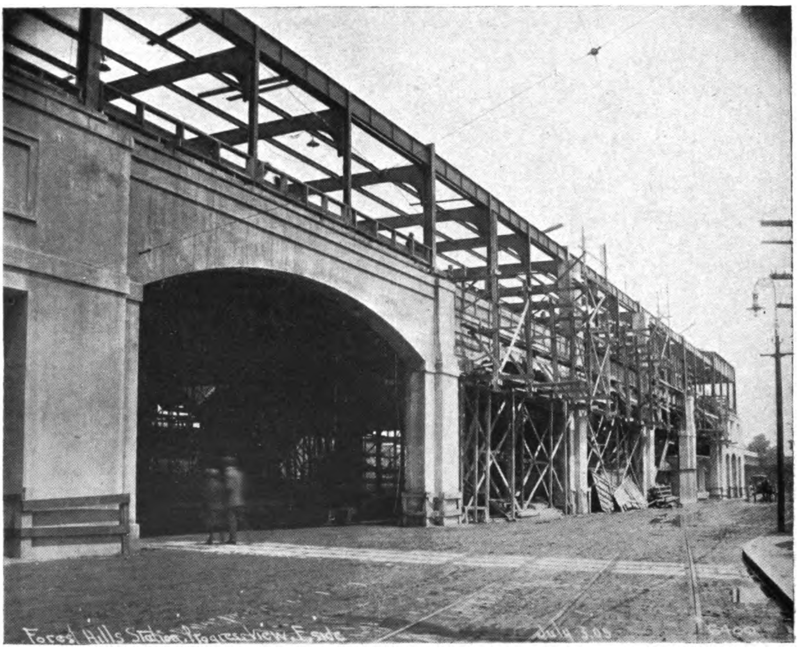



Fig. 5

EAST SIDE OF STATION, SHOWING INTERMEDIATE SIDE ARCHES, IN VARIOUS STAGES OF CONSTRUCTION

side of transverse girders, two sets of forms being used so that work was continuous. These forms were made at the company shops, being carefully designed for repeated use, ease in erection and removal. The forms had vertical posts at the corners of the columns, between which the sides set in three- (3) foot sections. Two-inch cypress lumber was used, and the completed form was held together with yokes of timber and steel rails.

The concrete was a 1-2-4 mixture with two- (2) inch stone, but the face was made of a special mixture six (6) inches thick, in order to get the desired finish. The method of placing this face was as follows: pieces of sheet iron twelve (12) inches deep and about the length of the sides of the octagon were set on edge around the inside of the form, and held away from it by lugs riveted to the plates. The heavy concrete was placed back of these for a height of a few inches, and then the special mixture, using ¼-inch stone, was placed between the plates and form and well spaded. The space back of the plates was then filled with the ordinary concrete, and the plate pulled up a little. This process was repeated until the form was filled, great care being taken to see that the concrete did not set at all, and in that way show horizontal joints.

After the column was filled, it was allowed to stand until it was able to support itself, about twenty-four hours in warm weather. After being stripped, the surface was scrubbed with wire brushes and water, until the stone in the concrete was exposed. This gave a rough stone-like finish and removed all form marks which, even with the greatest care, would otherwise have been somewhat in evidence. In addition to the structural steel columns, some additional rods were placed at the corners, both vertical and horizontal, to resist any tendency toward shrinkage cracks.

While the columns were being concreted the reinforcement on the girders was being placed. This consisted of Clinton wire cloth fastened on each side of the girder one inch from the web. Below the bottom of each pair of girders wire cloth was stretched, and up the outside, where the curved brackets are, a sheet of the same was also placed, so as to take the curve of the bracket and form a continuous surface. To form the arch rib at the center, some light curved angles were bolted to the under side of the middle girders, and covered with wire cloth.

In order not to show joints, each span had to be done without a stop from start to finish, necessitating, therefore, that the form be in place before work was started. Two complete sets of forms were made, one for each length of span. These were all made in the shops in sections of convenient size, and set up on the ground. It being necessary to keep the street clear,

all supports had to be from above. Therefore, hanger rods from the girders were run through timbers that set under the forms and supported them. The first part of the form that was put up in the span was the under side of the arch rib. Next to it came the side of the rib and then the forms for the flat arch. From these came the forms for the curved sides. All the surfaces of the forms were made of planed boards, well oiled in order to get a smooth surface.

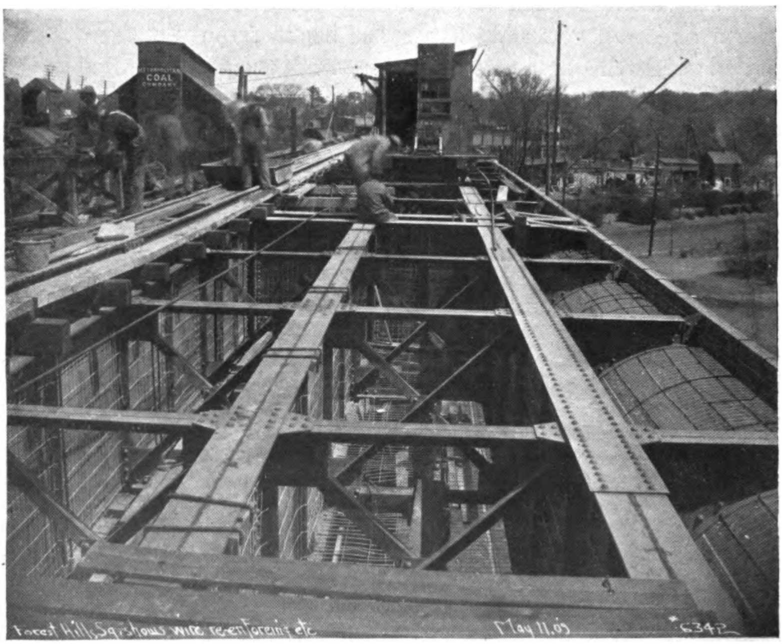



FIG. 6

TOP OF ARBORWAY STRUCTURE, SHOWING REINFORCEMENT

The surface of the forms was set about one inch from the wire cloth, and the concrete was put in only three (3) inches thick. The result, which from the outside looks like solid arches, was a three-inch skin of concrete reinforced with wire cloth, supported on the main girders.

The placing of the concrete was very difficult, as some of the spaces that had to be filled were small, and therefore it was almost impossible to be sure that the concrete reached all corners.

A rich mixture was used, being placed very wet, and most of it poured into the forms with coal hods. The forms for the skin were allowed to stand from four (4) to six (6) days, and removed to be set up in another span. When the outside skin had been finished, the webs of the girders were covered with concrete. As this surface is not visible, it was not necessary to be particular about the forms.

After a span was finished, the train floor was set; the floor itself is an eight- (8) inch slab, reinforced with ⅝-inch rods, and supported by the longitudinal girders. It extends to the outer edge of the curved brackets, where a panelled concrete parapet was erected; this latter is a thin wall, reinforced by vertical rods. Ducts for power cables are laid on each side of the train floor next to the parapet, and on them are the sidewalks.

An interesting feature of the work, and a difficult one to cope with, was the expansion. Each span of the arborway is free to move at its south end, but since the column is fixed, it was necessary to provide a joint in the concrete. This was done by allowing the south end of each span to extend beyond the north face of the column, the concrete of the fixed end being allowed to overlap this moving end. Separation was obtained with sheets of zinc.

As it was necessary to leave the forms on the arches several days, the concrete was set too hard to be scrubbed the way the columns were. The surface was hammered with pneumatic bush hammers, and in that way the same appearance of stone was obtained.

The work on the station was started shortly after that on the arborway and carried on at the same time. The first step was the construction of the pilasters, which were carried to the platform level. The arches between the side pilasters were then built, and a concrete floor put in the platform and train pit.

After this the pilasters were extended to the roof, and the north and south ends built. As soon as the platform was completed the carpenters and coppersmiths started on the sides and roof of the station, nearly completing their work by the time the concrete work was finished.

The forms for the pilasters were also made for repeated use, the back and front being in one piece each, and the sides in sections that could be placed as the concrete was put in. The pilasters were reinforced against shrinkage cracks in a similar way to the arborway columns, and the same method was used to obtain a face of different material from the body. However, only the first section, about 16 feet high, was treated this way. After that there was no attempt to place two kinds of concrete, ½-inch stone being used throughout.

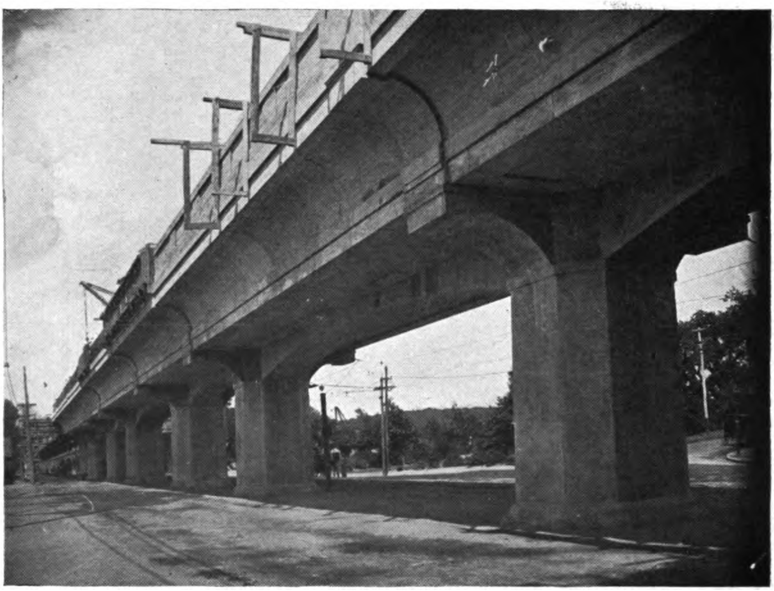


FIG. 7
ARBORWAY FROM WEST, SHOWING ARCH RIB AND FLAT ARCH

The side span at each end was built all together, both pilasters and the wall between being carried to the platform level in two steps. The forms for this work were built in place.

The side and end arches are hollow and about 3 feet wide. The ring and sides consist of 4 inches of concrete, reinforced with Clinton wire cloth which is attached to a light steel angle frame bolted to the station structure. A rough board form was built inside this framework to form the inside face of the

concrete, then the wire cloth was stretched, and the form for the outside was placed. These forms were made in panels, and were used several times. The concrete had to be made very thin, so that in pouring through the top of the form it would reach all corners. The forms were generally stripped in twenty-four hours, and the concrete surface scrubbed with wire brushes and water.

After the platform was in, the pilasters were all continued to the roof, the two end ones on each side being larger than the intermediate ones. Above the roof the tops of these larger ones were cast in place, but the tops of the smaller ones were cast in a plaster-of-Paris mould and set afterwards.

The platform of the station is a 4-inch concrete slab, reinforced with wire cloth supported on floor beams. To avoid the slipping of passengers, an attempt was made to get different degrees of roughness on the surface of the slab, as the edge of the platform was approached.

The floor of the train pit is also a concrete slab varying from 4 to 6 inches thick, and reinforced with ½-inch corrugated bars. The rail is carried on a wooden stringer that rests on the concrete directly over the longitudinal beam.

Entrance to the station is from the ground underneath, where the surface cars discharge passengers on a platform running the entire length of the station. Two flights of stairs and an escalator carry the passengers to the station platform itself.

Passengers leaving the station use stairs to the lower level, where surface cars may be taken on a platform separate from the inbound traffic.

Throughout the work great care was taken to get good architectural effects, all lines and arris being made as true and sharp as is possible in concrete work.

An interesting feature of the work was the handling of concrete to place. As the entire work was over a crowded street, it was important that the concrete should not drop. The mixer was situated on private land near the north end of the arborway structure, and the concrete was discharged into buckets holding one batch. These buckets were then picked up by derrick and swung to the top of the structure, where a special concrete car, that could dump either at the side or forward,

received it. This car then dumped the concrete at any desired point into large iron pans, from which it was distributed to the forms. When it was necessary to have very wet concrete, these pans enabled the men to add water without the danger of drip.

The station concrete was dumped in drop-bottom wagons, and taken to the middle of the station. There it was dumped onto a large sheet iron plate and thence into a concrete car on an elevator. The car was hoisted to platform level, and from there the operation was similar to that on the arborway.

The completed work is all that was desired, and is especially successful in regard to noiselessness of the concrete structure.

# HARVARD ENGINEERING JOURNAL

A QUARTERLY

DEVOTED TO THE INTERESTS OF ENGINEERING AND ARCHITECTURE AT HARVARD UNIVERSITY

THE OFFICIAL ORGAN OF THE ASSOCIATION OF HARVARD ENGINEERS

Published four times during the college year by the Board of Editors of the Harvard Engineering Journal.



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| Single copies . . . . . . . . . . | .35 |

Address all communications:—
HARVARD ENGINEERING JOURNAL,
Room 218. Pierce Hall,
Cambridge, Mass.

Entered at the Post Office, Boston, Mass., as second-class mail matter June 5, 1902.

## ENGINEERING SOCIETY

The second meeting of the year was held Thursday, December 2, in room 110, Pierce Hall. Mr. R. E. Miller, through the courtesy of the Westinghouse Air Brake Company, gave an illustrated lecture on "What Stops a Train?" Mr. Miller first outlined the part which Mr. George Westinghouse had in the invention and perfection of the air brake. Next a short

description of the Westinghouse Company's shops and their surroundings, at Wilmerding, Pa., was given. After Mr. Miller had described and illustrated the draft gear, he proceeded to a brief history of the brake and its application. The first Westinghouse air brake, the so-called "straight" air brake, came out in 1869. Continual improvements have been made in the air brake since its invention, including the use of but one hose between cars, the invention of the triple valve and its later improvements, and the storage of braking power on each car. In spite of the increase in the weight and speed of rolling stock, a decrease in the length and time of stop has been obtained. Results of practical tests at Absegon, N. J., and Toledo, Ohio, were shown. Mr. Miller outlined the improvement and enlargement of the air pump, and described the electric control of the air, which makes braking simultaneous throughout the train. He closed with a description of the magnetic brake and its application. After the lecture the meeting adjourned to room 213, where light refreshments and a social hour were enjoyed.

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## CIVIL ENGINEERING CLUB

The second meeting of the club was held December 14. Mr. H. U. Ransom gave a very interesting talk on the work on the Cambridge subway, explaining some of the difficulties encountered in trench construction, and ways of overcoming them. After the meeting refreshments were served in the social hall, where the members enjoyed the rest of the evening.

A. Arellano, *Secretary.*

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## ELECTRICAL CLUB

The Electrical Club held its first meeting of the year on December 9, 1909, at Professor C. A. Adams' house, 13 Farrar Street, Cambridge. Professors Clifford, Kennelly, and Adams were the speakers: the subject matter of their talks related to the general welfare and advancement of the men studying in the Electrical Department. Professor Adams read a number

of interesting letters from former students. These letters served admirably to show the kind of work Harvard Electrical Engineering graduates are now doing. After the general meeting Mrs. Adams and Mrs. Clifford served refreshments in the dining-room, and did much to make the men feel at home and to make the club a social unit.

At a previous business meeting, held in Pierce Hall, the following officers for the year 1909-10 were elected: president, W. P. Sheppard; secretary, C. D. Nourse; Treasurer, A. M. Sweeney.

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## BOOK REVIEW

THE ELEMENTS OF MECHANICS OF MATERIALS. By C. E. Houghton. [Associate Professor of Mechanical Engineering, New York University.]

This small volume is what its title indicates, an elementary text-book on Resistance of Materials. The notation and general arrangement are such as to remind the student of Merriman's "Mechanics of Materials," which is easily consulted as a reference book, but the explanations are clearer and simpler in many cases. There are eight chapters covering the ordinary simple stresses to which structures are subjected in service, and the book as a whole is well adapted to teaching the elements of the subject. At the same time there are a few omissions that might well have been supplied even at the expense of another chapter; for instance, the treatment of stresses in beams applies only to those whose cross-sections are symmetrical about the plane of the load. This omission is natural enough, as few text-books that make much larger pretensions touch the unsymmetrical sections as in any way exceptional. It would seem, also, that in a text-book intended for all engineers, there might well have been fuller reference to crank-shafts and other parts of machinery.

The book is excellent in its way, and it will be found useful to engineers in practise as well as to students in colleges. The problems add greatly to its value, and the tabulation of formulas in the back of the book forms a first-rate summary of results.

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